MASTER OF SCIENCE

Vein Pattern Analysis - A comparison of two vein imaging modalities

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Award date:
2014

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070004052

Centre for Anatomy and Human Identification

Submitted for the degree of Masters by Research

April 2014

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Acknowledgements

I would like to express my deepest gratitude to my supervisors, Professor Sue Black and Doctor Helen Meadows, for without their support and invaluable guidance this project would not have been possible. I have been honoured to work with these highly talented individuals who are at the forefront of Vein Pattern Analysis research for use in forensic human identification. Additionally I extend my thanks to Professor Steve Hubbard for his patient and dynamic instruction in statistical analysis.

Thanks go to the participants of this study without whom this research would not have been possible.

A huge debt is owed to Miss Harriet Stratton, Dr Catriona Davies and Dr Sarah Sulaiman for their guidance, support and patience in many matters, and to Mrs Vivienne Maguire for organising all of my meetings.

Declaration

I (Miss Rachel Sarah Aiken) declare that I am the sole author of this thesis, that, unless otherwise stated, all references cited have been consulted by me; that the work of which this thesis is a record has been done by me, and that it has not previously been accepted for a higher degree.

Signed ______________________ Date___________________

(Rachel Aiken)

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List of Abbreviations

CAHId: Centre for Anatomy and Human Identification

dl: Day Light

DSLR: Digital Single Lens Reflex

IR: Infrared

MP: Mega Pixels

NIR: Near Infrared

PI: Principal Investigator

VPA: Vein Pattern Analysis

VV: VeinViewer

1. Introduction

In essence biometrics are used to assist with determination of identity through the measurement and analysis of biological and behavioural features. The human hand contains a number of physical features that have been utilised for biometric identification systems via both manual and automated methods, the most well known of which are the friction ridges of the epidermis of the fingers, known commonly as finger prints (Deravi, 2008).

Traditionally utilised as a biometric identifier for security systems, Vein Pattern Analysis (VPA) has emerged as a novel scientific technique for use in the forensic arena, with the subcutaneous venous pattern of the hand gaining recognition as a means of biometric identification in the year 2000 following the publication of an article by Im *et al* (2000).

The introduction of VPA as a method of forensic human identification was introduced to the UK legal system in 2007 and this technique has been utilised in the comparison of suspect and offender images as an aid to establishing the identity of a perpetrator.

The technique of VPA has been recognised as a useful tool for forensic human identification in cases of child sexual abuse, where associated paedopornographic material often includes images of the offender’s genitals, forearms and hands.

An example of the utility of VPA in such circumstances is outlined in the case of R vs. Mr C, where forensic practitioners from the Centre for Anatomy and Human Identification (CAHId) assisted in the assessment of indecent images of an adult male sexually abusing a female child. The images in question included various aspects of the hand of the offender and were analysed to determine if a comparison could be made between the offender images and those of an identified suspect. Although both the dorsal and palmar surfaces of the offender's hand could be seen in the images, only those of the dorsal surface were of sufficient quality for analysis. The offender images were isolated and enhanced using Adobe Photoshop®, with areas of anatomical interest including vascular pattern being highlighted. Analysis of the vein pattern visible in both suspect and offender images concluded that significant similarities were present, supporting the hypothesis that the suspect and offender were likely to be the same individual, with no evidence to suggest that the images represented a different individual. When presented with these findings, the suspect changed his plea to guilty for all 35 charges brought against him, receiving two years imprisonment and served with a Sexual Offenders Prevention order.

In addition to still images associated with cases of child sexual exploitation, advancing technology has seen a rise in the amount of video evidence presented in court. In the first case of this kind (2007), R v. Mr J involved video evidence captured on a webcam with infrared (IR) capabilities. Despite the low resolution of the webcam utilised to obtain the material, the infrared capabilities of the camera resulted in video evidence which clearly depicted the superficial vein pattern of the offender's forearm and the back of his leg. Stills from the video evidence were enhanced using Adobe Photoshop®, with the visible vein pattern being traced and the resultant pattern being compared with that obtained from images of the suspect obtained whilst in police custody. Analysis concluded that similarities present between the suspect and offender vein patterns could not allow the exclusion of the suspect from investigation. The strength of information obtained from the evidential

IR video, resulted in the employment of IR photography in subsequent vein pattern analysis research (Meadows, 2011).

Given the sensitive area in which this technique may be employed, coupled with the growing prevalence of associated cases, it is essential to explore the differing circumstances to which the method of VPA can be applied.

This thesis will build upon research previously conducted by the Centre for Anatomy and Human Identification (CAHId) in vein pattern analysis for forensic human identification.

The objective of this study is to assess the extent to which the superficial structures of the venous pattern of the dorsum of the hand can be visualised utilising a Digital Single Lens Reflex (DSLR) camera, compared to a commercially available VeinViewer recording device.

At present, all still images obtained of a suspect whilst in police custody are procured via the use of a DSLR camera. The use of this equipment in such instances is due to its availability in all police constabularies as it is considered an essential element of evidence gathering, primarily for recording evidence at scenes of crime and for use by the police surgeon in cases of physical assault (Home Office, 2007).

Previous research both in the fields of medical imaging and biometric technology, has determined that vein pattern data can be better visualised in images captured using Infrared (IR) photography compared to visible light imaging modalities (Zharov *et al.*, 2004; Bhattacharyya *et al.*, 2010). As a result, it has been proposed that the use of an infrared imaging device for gathering evidence from suspects whilst in custody may prove beneficial to cases requiring identification via means of VPA.

With an omnipresent focus on the accuracy of forensic science as a whole, it is essential that it can be demonstrated that methods of analysis are both accurate and based upon accepted scientific principles (National Research Council, 2009a). While both VPA and its underlying principles in human anatomy are widely accepted, it is the intention of this study to investigate which imaging modality provides the most consistent method for visualising the vein pattern for use in VPA. This research aims to compare the constancy with which features of the venous pattern of the dorsum of the hand can be identified using a DSLR camera with IR capabilities, and a VeinViewer device. DSLR cameras are the imagining device of choice for evidence gathering in police investigations, however the associated cost of an IR capable DSLR greatly exceeds that of a VeinViewer device which pending investigation into its effectiveness, may be introduced as a more cost effective alternative.

As this research is being conducted in conjunction with work on VPA in the investigation of child sexual exploitation cases, it is undertaken with reference to previous such cases analysed by experts at the Centre for Anatomy and Human Identification (CAHId) at the University of Dundee. At the time of writing, CAHId experts have been consulted on numerous cases requiring the identification of suspects from images of their hands. In these cases, all observed identifying features including both anatomical features, individuating marks (such as scars) and venous patterns have been utilised for the comparison of suspect and offender images. As with all evidence, the more corroborating features between suspect and offender images, the greater support of the hypotheses that the suspect and offender could be one and the same. As such, it is acknowledged that IR images could not be utilised in place of visible light images in cases where the original evidential images were created using visible light photography, but rather both types of image should be used in conjunction. For this reason this work will assess if it would be advantageous to upgrade current photographic equipment to DSLR cameras with IR capability, or if following cost benefit analysis, it would be more favourable to deploy the use of VeinViewer cameras as a more commercially available and affordable alternative, to be used in conjunction with current visible light imaging modalities.

The underlying objective of this study is therefore to determine which Infrared imaging modality (DSLR or VeinViewer) is capable of capturing the greatest amount of vein pattern information, from which detailed analysis can be based in an attempt to assist in forensic human identification.

2. Aims and Objectives

2.1. Aims

The aim of this research is to assess the viability of the VeinViewer camera as an alternative tool to a Digital Single Lens Reflex (DSLR) camera in the gathering of photographic vein pattern evidence from a suspect whilst in a custody suite.
This research will focus on the use of the VeinViewer camera in capture of images of the dorsum of the hand of a suspect for use in Vein Pattern Analysis (VPA).

Previous research such as that conducted by Meadows (2011) has determined that images captured using Infrared (IR) photographic devices have high utility in VPA, as the vein pattern can be visualised more readily, thus allowing any identifying features of the pattern to be recorded accurately. As a result, it has been proposed that the use of an infrared imaging device for gathering evidence from suspects whilst in custody might prove beneficial to cases requiring identification via means of VPA.

This research aims to compare the ability with which features of the venous pattern of the dorsum of the hand can be identified using a DSLR camera with IR capabilities and a VeinViewer device.

2.2. Objectives

This study will analyse the ability with which the venous pattern of the dorsum of the hand can be visualised using two types of IR imaging device; the VeinViewer imaging device and a DSLR camera with IR capabilities. The purpose of this research is to present recommendations for the use of the more accurate device for use in obtaining IR images of a suspect's hands whilst in the setting of a custody suite.

There are three primary objectives of this research:

1. To record visible vein pattern features of the dorsum of the hand using;

    a) VeinViewer

    b) DSLR camera with IR capabilities (in this instance a Fuji IS-1)

   Analysis is conducted by first creating an image database containing images of the dorsum of individuals' hands taken using each imaging modality.

   The vein pattern visible in each image is then traced following the method of Meadows (2011), with each feature identified in the tracings being subsequently recorded in a database.

2. To compare the ability of each imaging modality.

   This analysis is achieved by statistically comparing feature counts of images taken using each device, taking into account the variables of age, sex and ethnicity of participants, and lighting conditions. The resultant statistics are used as an indication of the ability of each device, with the highest feature counts being associated with the imaging device capable of visualising the most vein pattern data.

3. To provide a cost benefit analysis of each imaging device.

An analysis of equipment and training costs associated with each device are then presented, with the resultant cost benefit analysis resulting in a recommendation for the implementation of the more successful method.

2.3. Hypothesis

The VeinViewer is marketed as vein visualisation equipment, as such it is hypothesised that this equipment has the ability to identify a greater amount of vein pattern information than the DSLR camera which is not designed for this sole purpose. At a retail price of £60, compared to £280 of the DSLR, it is proposed that the VeinViewer could be utilised as a low cost alternative to the DSLR for the gathering of photographic vein pattern evidence from a suspect whilst in the setting of the custody suite.

In summary, it is hypothesised that there is no difference in image quality or data acquisition between a DSLR camera with IR capability and a VeinViewer device.

3. The Role of Photography in Forensic Identification

The fundamental basis of this research is the comparison of two different imaging modalities to assess their utility in forensic human identification. In order to fulfil the remit of this study, the role of photography in human identification will be discussed.

3.1. Forensic Photography

The disciplines encompassed by the term "Forensic Science" have a common aim of serving the judicial process (UK Government, 2005a; Roux *et al.*, 2012). The forensic process is in essence the application of scientific techniques and inferences to criminal investigations with the aim of supporting investigation and providing intelligence (Yoward, 2012). Photography has proven itself invaluable in forensic application as it enables evidence to be documented, with fine detail being recorded (Chiao *et al.*, 2013), and in the case of certain types of photography, the capture of information not readily visible to the naked human eye (Porter, 2012). This utility has led to photography being viewed as an "indispensable aid" to investigations (Scott, 1938).

Numerous authors have noted the significance of photography in the investigation of crime since its introduction to law enforcement in the late 1800s (Rohde, 2000; Edmond *et al.*, 2009; Nickell, 2010a; Chiao *et al.*, 2013), with digital photography becoming increasingly important in the forensic arena (Wall, 2006; Baker *et al.*, 2012). Photography was introduced into the domain of policing in the late 1800s as an addition to anthropometry (Edmond *et al.*, 2009). The Bertillonage system of anthropometry introduced in 1882, aimed to distinguish individuals on the basis of a series of defined physical measurements (Pavlich, 2009). These measurements were recorded in conjunction with written descriptions of the individual and supplemented with photographs both from the front and in profile (Pavlich, 2009; Duncan, 2010). Since this early use as a supplementary tool, criminal photography has extended from a permanent record of evidence to now encompass surveillance, detection and deterrence of crime (Russ, 2001). This implementation of forensic photography in wider areas of police work can be accredited to the development of more sophisticated, user friendly models of camera (Rohde, 2000).

The aim of the forensic photographer is to "gather images in support of the criminal justice system" (Roberts and Marquez-Grant, 2012). This support can be provided in a number of ways, through crime scene photographs, suspect photographs and analysis of offender images. Regardless of their intended purpose, all images captured may be utilised as exhibits in an investigation and so must be recorded, handled and secured in a manner to ensure evidential integrity and continuity (Roberts and Marquez-Grant, 2012; Chiao *et al.*, 2013).

From primitive photographs developed on glass plates, to the film free camera, photography as a field has advanced rapidly (Nickell, 2010b), with digital cameras being able to produce high quality images with reduced input from the user (Russ, 2001). Digital photography provides an efficient and reliable means of detailing evidence which can be easily viewed, stored, reproduced, and disseminated. It has been noted that such instantaneous "playback" of images enables the quality of images to be assessed, with any unsatisfactory images being easily repeated to ensure all available information is recorded to the highest standards, resulting in an accurate record (Goldthorpe and McConnell, 2000). With this rapid advancement of photographic technology, high resolution imaging equipment capable of capturing both still and video images is readily available not only to police forces, but also to the general public (Goldthorpe and McConnell, 2000).

3.2. Photographic Images as Evidence

Photography has long been utilised in criminal investigations to document and be a resource for subsequent analysis and presentation of evidence (Porter and Kennedy, 2012), and has proven itself an effective aid for investigation (Feigenson, 2010; Porter, 2011).

Primarily, photography is utilised as a tool for evidence-gathering, with the resultant images being utilised to inform individuals involved in the investigation of the crime such as officers of the law, experts, or witnesses (Chiao *et al.*, 2013). Photographs of crime scenes are often presented in court to enable the scene at the time of the offence in question to be reproduced (Porter and Kennedy, 2012), with this use being deemed especially effective in cases of trial by jury (Scott, 1938).

Photographs or videos can also serve as witness evidence, in that they may act as a record of the events as they occurred (Chiao *et al.*, 2013). A common example of this type of video evidence is CCTV footage, or video evidence captured using “smart phones” (Goldthorpe and McConnell, 2000; Porter, 2012). A combination of both CCTV and smart phone video were utilised in the trial of Michael Adebolajo and Michael Adebowale, who were found guilty of the murder of fusilier Lee Rigby; CCTV footage captured the impact of the car, with mobile phone footage taken by eye witnesses documenting the attack, and confession of Mr Adebolajo as he wielded the murder weapon at the scene of the crime (BBC News, 2013; Telegraph, 2013).

Photographic images are also utilised by the judicial system as recorded evidence for "the identification of persons, objects and actions" (Russ, 2001). Images obtained for identification purposes generally act to record distinctive features such as scars, birthmarks or tattoos. In addition to these permanent features, temporary identifiers such as injuries or defensive wounds are also noted (Rohde, 2000).

Utilising photographic evidence for identification purposes has three primary objectives (Russ, 2001);

1. To enable assignment of identity of a perpetrator / victim
2. To obtain an admission of guilt
3. To convince a jury that the correct person has been apprehended

As with all forms of evidence, photographs must be collected and stored in a manner deemed appropriate according to evidential standards (Feigenson, 2010). This requirement is essential to ensure continuity and integrity of evidence, to not jeopardise its admissibility in a court of law (Goldthorpe and McConnell, 2000; Porter, 2011; Chiao *et al.*, 2013). The main aim of a forensic photographer is to produce images which are "crisp and clear", regardless of lighting and/or environmental conditions. In order to achieve this aim, it is accepted that an in-depth knowledge of the imaging device, and the essentials of photography itself are necessary (Russ, 2001; Yoward, 2012). This requirement is demonstrated in court room questioning where the forensic photographer is often asked to provide explanations of an image in technical terms (Yoward, 2012).

3.3. Analysing Photographic Evidence

Regardless of the type of imaging device utilised, or the resulting image format, forensic analysis of images is performed with one of four aims in mind (Baker *et al.*, 2012), these are;

1. To provide evidence for inclusion or exclusion of an individual in further investigation
2. To determine the origin of the image in terms of imaging device
3. To determine if images have been altered
4. To determine if unknown or corrupted files can be converted or repaired to facilitate analysis

In the context of this research, it is the first objective which will be explored in depth.

3.4. Collecting photographic evidence in the custody suite

The 1984 Police and Criminal Evidence Act (PACE) outlines the powers of police during investigation, including the acts of arrest, detention, interrogation, entry and search of premises and physical searches of persons as well as the taking of samples (UK Government, 1984). The UK legal system dictates that a suspect may be held in custody for a period of 24 hours, with this being extended up to 36 or 96 hours if the nature of the crime is deemed serious, for example if you are suspected of being guilty of murder (Russ, 2001). Whilst in custody, the police have the right to obtain physical evidence without the need for a warrant as covered by PACE. This evidence includes photographs, fingerprints and samples of DNA (Russ, 2001).

3.5 Collecting video evidence in the custody suite

Imaging devices in the form of CCTV have been employed in police custody suites since the beginning of the 1990s. This technology has been described as an “invaluable tool” in the administration of custody suites, predominantly in cases where vulnerable detainees are involved. It is argued that such a measure is in place to enable police officers to “effectively discharge their duty of care” to individuals in custody who may be at an increased risk from personal harm (Thames Valley Police, 2008). The underlying principle for use of recording devices is to provide both the individual in custody, and personnel involved in the detention process with a means of recording treatment (Thames Valley Police, 2008).

Whilst CCTV recordings of custody suites are not directly intended as an evidence gathering tool, in certain circumstances such recordings may contain evidential material that may be used to assist in the investigation of a case (Thames Valley Police, 2008). As such, this material must be handled in a manner which adheres to the provisions outlined in the Police and Criminal Evidence Act (UK Government, 1984) and the Criminal Procedure and Investigation Act (UK Government, 1996).

Guidelines have also been issued regarding the placement of such recording equipment, stating that the camera should be visible so as to alert the detainee of its presence and its location should be out of reach where it may be not be intentionally disturbed. In terms of placement it is also stated that recording equipment should not be located in areas which may breach the privacy of a detainee such as police surgeons examination rooms and those utilised for legal consultation. At present, general recordings (bearing no evidential value) collected during time in custody will be held for a period of 30 days, after which they should be written over and made irrecoverable. Recordings which contain potential evidence may be kept for a period exceeding this in order to preserve said evidence. The circumstances under which such recordings may be retained are detailed below;

(a) Where the recording is identified as containing evidence;

(b) Where a complaint is made against police or a contractor (for example, in relation to a Custody Assistant operating within a force Custody Suite);

(c) Where there is an occurrence, which, in the opinion of the custody officer, may result in a complaint or civil action;

(d) Where the duty inspector, senior investigating officer, an investigating officer from the force Professional Standards Department, or an investigator from the Independent Police Complaints Authority (IPCC) directs retention (Thames Valley Police, 2008).

In instances where it is agreed from the outset of custody that any recorded material will be of evidential use, the master recording will be treated as a production (exhibit), in that once recording is completed, a copy will be made, with the master copy being sealed in an evidence bag and chain of custody and security procedures being observed to ensure the integrity of the production (exhibit).

Whilst regulations are in place for the capture of CCTV video recordings, procedural changes would be required to obtain VeinViewer images, including close up video recordings of the dorsum of a suspect’s hands.

4. Photographic Evidence in cases of Child Sexual Exploitation

With the advancement of the internet and increased ease of access, classical disciplines are having to develop methods with which to tackle the emerging area of "cyber-crime" (Quayle and Taylor, 2002a; Moore *et al.*, 2009). The parallel advances of photography and the internet have resulted in the evolution of child exploitation from the "clandestine physical exchange" of photographic hard copies to the instantaneous transmission of images between offenders which is not limited by geographical boundaries (Hirschfeld, 2005).

In cases of child exploitation where photographic evidence exists in the form of indecent images, the aim of investigating officers is to determine if the suspect in custody can be excluded from investigation on the basis of comparison of anatomical features with those of the perpetrator visible in the indecent images (Black *et al.*, 2013).

It is important to establish if the individual present in such images is the suspect as sentences for possession of indecent images and child sexual exploitation vary in terms of severity and associated sentencing (UK Government, 2003; Howitt and Sheldon, 2007; Cohen-Almagor, 2013). If it is proven that the possessor and creator of the images are one and the same, then a more serious charge of creating indecent images of a minor will be levied (UK Government, 1996). This "chain of liability" from the creator of the image to the end audience is outlined effectively by the recent report by the Cabinet Office, entitled "Progress against the Objectives of the National Cyber Security Strategy" (UK Government, 2013a), which states that the creators of such images could also be referred to as "abusers". Regardless of position in this chain of liability, each action from "production, distribution, dissemination through to transmission" of child pornography are criminalized in all EU member states (UK Government, 2013a).

In cases of child exploitation, digital photographs of anatomical regions of a suspect have been used successfully to highlight similarities between suspect and offender, clear suspects of any wrongdoing, and even secure convictions whereby suspects have changed their plea to guilty when presented with the evidence. Such cases exemplify two of the three primary aims of photographic evidence used in forensic cases (Feigenson, 2010; Yoward, 2012);

1. To enable assignment of identity of a perpetrator
2. To persuade the perpetrator to confess guilt

From previous cases, recorded images have proven invaluable to the identification of suspects in cases of child pornography. As perpetrators are aware that their actions are illegal, they take care not to expose their facial features in recorded images to avoid identification. This shared characteristic of offenders appearing in child exploitation material resulted in forensic identification experts being approached to assist in assigning identity to offenders based on the anatomical regions visible.

4.1. Child Sexual Exploitation

Discussions of child sexual exploitation have become increasingly prevalent in modern society. This topic has become somewhat omnipresent in the press, with new headlines daily reporting cases of child sexual exploitation from across the globe (NBC News, 2013; Usborne, 2013; BBC News, 2014a; BBC News, 2014b), and denouncing high profile individuals as paedophiles (BBC Wales, 2013). Both child protection charities and law enforcement agencies have reported an increase in the number of referrals relating to cases of child sexual abuse, arguably as a result of awareness generated during these celebrity cases (BBC Wales, 2013; Ramesah, 2013; The Guardian, 2013).

The term "Child Sexual Exploitation" encompasses the crimes of child pornography, child prostitution, and the trafficking of children for sexual purposes (Estes and Weiner, 2001; Chase and Statham, 2005). The exploitation of children for sexual purposes is not a modern day concept, with the creation of child welfare legislation in the 19th century demonstrating such concerns of the time (McClelland and Newell, 2013). More recently, The Children Act (2004) was established to promote and safeguard the views and interests of children, and make provision for services of support for children and young people (UK Government, 2004).

The human rights agreement produced by the United Nations entitled Convention on the Rights of the Child (United Nations, 1989), combined with the supplementary Optional Protocol to the Convention on the Rights of the Child on the Sale of Children, Child Prostitution and Child Pornography (United Nations, 2000), are to date the most widely accepted legal statutes created for the purpose of protecting children from sexual exploitation (O'Donnell and Milner, 2007). This statement is supported by the fact that over 100 countries have endorsed this international standard (UNICEF, 2005).

Article 34 of the United Nations entitled Convention on the Rights of the Child (UNCRC) outlines that all included nations take appropriate measures to protect children from sexual abuse and exploitation of all forms, with the 3 subsections detailing the activities from which the child should be protected;

(a) the inducement or coercion of a child to engage in any unlawful sexual activity

(b) the exploitative use of children in prostitution or other unlawful sexual practices

(c) the exploitative use of children in pornographic performances and materials

4.2. Paedophilia

According to the current UK Legal definition, as stated in the Sex Offenders Act (1997), paedophilia is “a sexual relationship between an individual 18 years of age or over and a child (under 16 years old)” (UK Government, 1997). A paedophile is therefore the party aged 18 years or older, who practices paedophilia. The term “child sex offender” is often used in place of the term “paedophile”, with the definition encompassing individuals who view, store and distribute images of children which are sexually explicit in nature (Cohen-Almagor, 2013). The term “online”, proceeding “child sex offender”, indicates that the internet is employed by the individual to achieve these means. A report produced by the US Senate Permanent Subcommittee entitled Investigations on Child Pornography and Paedophilia stated that “no single characteristic of paedophilia is more pervasive than the obsession with child pornography” (US Department of Justice, 2010).

4.3. Child Pornography

Child pornography is by definition any pornographic material depicting a child involved in any sexual conduct whatsoever (Akdeniz, 2008), with Article 2, subsection (c) of the United Nations' Optional Protocol to the Convention of the Rights of the Child (UNCRC), on the Sale of Children, Child Prostitution and Child Pornography (2000) providing a concise description of child pornography as "any representation, by whatever means, of a child engaged in real or simulated explicit sexual activities or any representation of the sexual parts of a child for primarily sexual purposes".

This definition is further expanded in the European Union's Framework Decision on Combating Sexual Exploitation and Child Pornography (January 2004), stating that child pornography is pornographic material that visually depicts or represents;

> (i) a real child involved or engaged in sexually explicit conduct, including lascivious exhibition of the genitals or pubic area of a child; or
>
> (ii) a real person appearing to be a child involved or engaged in the conduct mentioned in (i); or
>
> (iii) realistic images of a non-existent child involved or engaged in the conduct mentioned in (i).

In the UK, child pornography is listed as an offence in the Sexual Offences Act 2003 (Part 1, Section 48), stating that;

A person (A) commits an offence if—

(a) he intentionally causes or incites another person (B) to become a prostitute, or to be involved in pornography, in any part of the world, and

(b) either—

(i) B is under 18, and A does not reasonably believe that B is 18 or over, or

(ii) B is under 13.

The abuse and exploitation of children in this manner has grave impacts upon the wellbeing of the victims; both physical and psychological. Child pornography has been described in a report by the US Senate as “a particularly pernicious evil, something that no civilised society can or should tolerate. It abuses, degrades and exploits the weakest and most vulnerable members of our society; our children” (US Senate, 1996).

The criminalization of child pornography acts with the aim of preventing such abuse and the harm caused by the recording and dissemination of paedophilic material (Goode, 2010). Such material serves as a permanent record of the exploitation and sexual abuse suffered by the child or children depicted in such images (US Senate, 1996; Internet Watch Foundadtion, 2012).

In addition to the personal harm caused to the child involved in such images, it has also been noted that child pornography is often utilised by paedophiles to groom children into participating in physical abuse and indecent images (US Senate, 1996; Quayle and Taylor, 2002b; Akdeniz, 2008). This cycle of abuse and coercion is summarised in Figure 1 below.

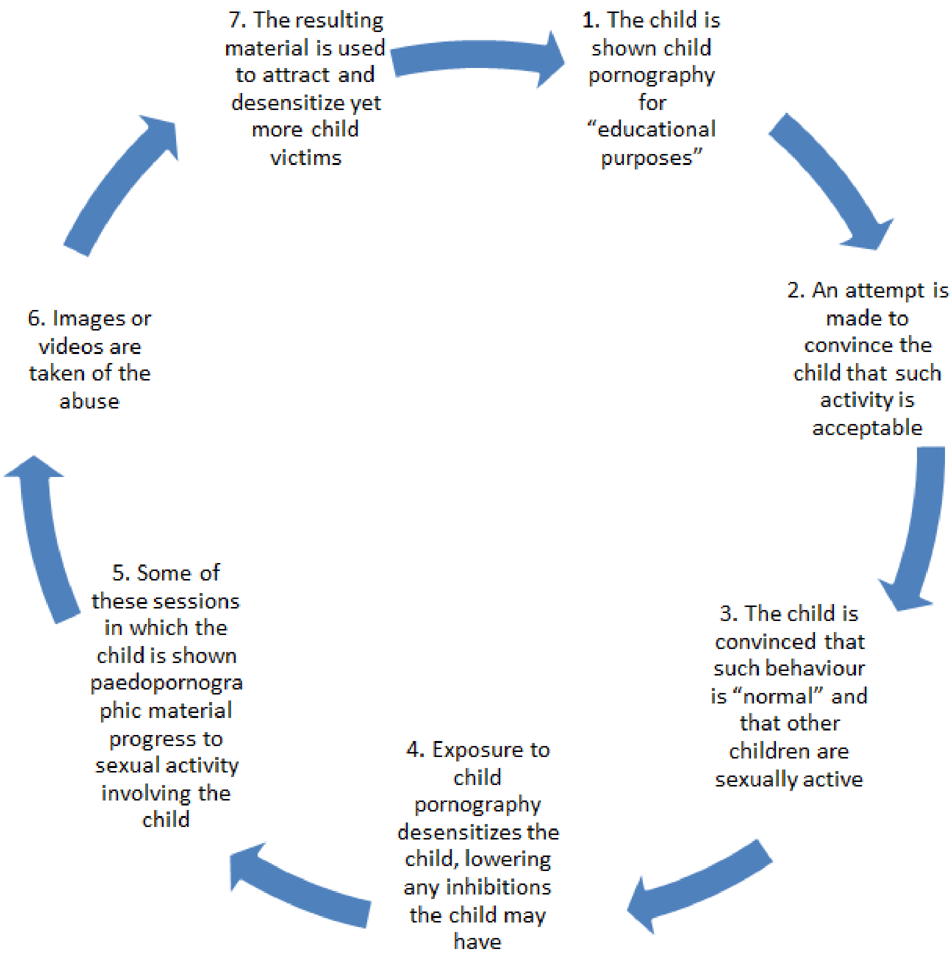


Figure 1. Cycle of abuse using child pornography - adapted from Goode (2010)

This observed cycle acts as a primary argument to justify the prosecution of individuals in possession of child pornography.

The creation, possession and distribution of pseudo-images and computer generated images depicting child sexual abuse and exploitation are also consequently criminalized in many jurisdictions. Although such pseudo-images are created without using any living children in the process, but rather superimpose the face of a child onto that of a consenting adult engaging in sexual conduct, the perceived outcome is arguably similar to paedophilic images depicting the abuse and exploitation of real children (Akdeniz, 2008).

Legislation relating to child pornography was developed for the UK legal system in the 1970s due to the rising concern regarding the sexual abuse of children and their exploitation through pornographic material. The Protection of Children Act (1978) was created in response to such concerns, providing a specific legal framework regarding the issue of child pornography. This legislation is constantly amended to keep up to date with technological advances in imaging. Prior to the Protection of Children Act (1978), sexually explicit images of children were criminalised under the Obscene Publications Acts of 1959 and 1964 (UK Government, 1959; UK Government, 1964). With the advancement of the technological age this legislation was amended by the Criminal Justice and Public Order Act (1994) to include indecent images in data format. Currently, the severity of child sexual exploitation images and the associated sentencing of offenders are based upon the COPINE scale and its derivatives.

4.4. The COPINE Scale

The Combating Paedophile Information Networks in Europe (COPINE) project was established in 1997 at University College Cork, in associated with the Paedophile Unit of the London Metropolitan Police, as an organisation to research online child sexual offences (Quayle and Taylor, 2002a). The main aim of the project was to establish an archive of child sexual abuse images for the purpose of victim identification (Howitt and Sheldon, 2007), therein promoting the online protection of children (Meridan *et al.*, 2011). The scale is now widely used as a typology in research and studies of child sexual exploitation material (Williams, 2004; Meridan *et al.*, 2011; Quayle, 2011). The initial database for victim identification created by COPINE has since been integrated into the Interpol Abuse Image Database (Beech *et al.*, 2008)

The COPINE scale was created as a means to categorize child abuse images according to extremity of content, from non-sexualised, to those depicting acts of torture and/or bestiality (Meridan *et al.*, 2011). The COPINE scale is in essence a grading system of 10 levels of image content, which are described and assigned to a scale level. Images are classified in terms of indecency, with assignment of images from the least extreme (Level 1) to the most extreme (Level 10) (Howitt and Sheldon, 2007). Each level is named, with a description of the type of image associated being described. This scale also takes context into consideration, for example Level 1 images whilst not in themselves pornographic in nature, such low level images possessed by an adult with sexual interest in minors are considered as child pornography. The inclusion of such image types in the COPINE scale reflects the use of such images by paedophiles as an aid to "masturbatory fantasy" (Quayle and Taylor, 2002a).

The COPINE scale has been described as an "invaluable overview of child pornography", which assists law enforcement agencies in categorizing images (Howitt and Sheldon, 2007). It must be noted however that the original COPINE scale is not intended to classify the severity of offence, but rather to act as a description of the image content. Due to the sensitive nature of such images, this categorization results in officials of the law being able to draw up appropriate charges without the images being viewed by an excessive number of individuals.

Table 1. . COPINE typology with additional explanation levels (Adapted from Meridan et al. 2011 and Howitt and Sheldon 2007)

Levels	Classification Criteria	Description
1. Indicative	Non-erotic, non-sexualised images of children in underwear whilst swimming or playing etc. Can be from commercial sources or family pictures. Context and/or organisation of images indicates inappropriateness.	Images of minors in daily situations. May be clothed or in underwear/swimwear. Typically pictures from family albums, catalogues or brochures.
2. Nudist	Semi- or fully naked children in a general nudist environment. Images from legitimate sources i.e. family photographs from a nudist holiday resort or commercial images for such a location.	Images of minors in daily situations where (semi-) nudity is considered normal, e.g. in the bath or at the beach. Typically pictures from family albums, catalogues or brochures.
3. Erotica	Photographs taken surreptitiously of children in play areas or other "safe" environments. Children in underwear or varying degrees	Images of minors in daily situations where (semi-) nudity is considered normal, e.g. in the bath or at the beach. Images acquired without the

	of nakedness.	knowledge of the subject.
4. Posing	Images of children in deliberately posed positions. Context and/or organisation of images indicate sexual interest.	Images in which the minor is knowingly posed for the camera. The image itself is not sexualised on its own.
5. Erotic Posing	Images of children posed in a deliberately sexualised or provocative manner	Images in which the minor is knowingly posed for the camera in order to produce sexualised images. Examples include poses in which the child is pretending to be a model, film star or porn star.
6. Explicit Erotic Posing	Images in which the genital area of the child is emphasised. Can be either clothed or naked.	Images of minors in which the main attention lies on a boy's penis, or a girl's vagina and/or breasts.
7. Explicit Sexual Activity	Images which depict inappropriate touching, mutual or self-masturbation, oral sex and intercourse by a child. No adults involved in image.	Images of minors engaged in sexual activity, either alone or with other minors.
8. Assault	Images depicting children as the subject of sexual assault, including digital touching. Adult involvement.	Images of minors depicting the minor touching and adult or an adult touching a child in a sexual manner.
9. Gross Assault	Grossly obscene images of the sexual assault of minors, involving penetrative sex, masturbation or oral sex.	Images of minors engaged in sexual activity with an adult.
10. Sadistic / Bestiality	a.) Images depicting a minor being subjected to some degree of pain; tied, bound, beaten, whipped, or implication of other pain. b.) Involvement of an animal in sexual relation with the minor	a.) Images of minors being subjected to various degree of torture. b.) Images of minors engaged in sexual activity with an animal.

The seriousness of offences in relation of child pornography are classified according to three primary criteria;

1. The quantity of material produced/possessed
2. The quality of material produced/possessed
3. The use of material

In order to determine the seriousness of an offence relating to child pornography, the nature of the material and the offender’s involvement with it are considered as primary determinant factors (Crown Prosecution Service, 2012). These factors were set in UK law in the case of *R v Oliver, Hartrey and Baldwin [2003] 1 Cr App R 28*, with ruling comments linking the severity of an offence to the proximity of the offender to the original abuse from which the image was created. Importantly, initial distinction is made between producers of child sexual exploitation material, those who download and possess said material, and those who are responsible for its distribution. The adjusted COPINE scale assists in deciding an adequate sentence for all the aforementioned groups, with specific factors taken into consideration when deciding the sentencing of an online child sexual offender, including; “the number of images manufactured/produced/distributed/possessed” by the offender, and the level of extremity of the act(s) depicted in said images (International Centre for Missing and Exploited Children, 2012).

Since its introduction as a classification tool, the COPINE scale has been adjusted for use in sentencing of offenders. It has been described as an aid “to inform legal decisions” relating to child sex offenders (Meridan *et al.*, 2011). The resultant sentencing guidelines produced by the Sentencing Advisory Panel incorporate only the later five levels of the original COPINE scale, with level 5 being the most serious as an equivalent to level 10 of the COPINE scale (Sentencing Council, 2013).

Table 2. Sentencing Council classification of the Seriousness of Indecent images of children (Meridan et al., 2011)

Level	Classification
One	Images of erotic posing, with no sexual activity
Two	Non-penetrative sexual activities between children, or solo masturbation by a child
Three	Non-penetrative sexual activity between adults and children
Four	Penetrative sexual activity involving a child or children, or both children and adults
Five	Sadism/Torture or involving the penetration of, or by, an animal

A revision of these guidelines by the now named Sentencing Council, was published in December 2013, with the new definitive guideline for judges and magistrates on the sentencing of sexual offences coming into effect on the 1st of April 2014 (Sentencing Council, 2007). The new set of guidelines aims to simplify the assessment of indecent images, which in turn will enable analysis of such evidence to be conducted more easily during the compilation of the case for prosecution. The new guidelines place increased emphasis on the level of involvement the defendant has with the images; creating, distribution or possessing. It is suggested that this will aid in assessing the offending behaviours of the defendant and thus enable appropriate sentencing.

As demonstrated by the sentencing structure in place, the creation of child pornographic images is not a new occurrence, however the emergence and advancement of the internet and computer technology has seen an increase in the prevalence of such material readily available and relatively accessible (Quayle and Taylor, 2002a).

4.5. Paedophilia and the Internet

With the internet becoming more integral to everyday living, its use is employed by many individuals for a wide range of purposes (Hoffman *et al.*, 2004). Computers are now capable of processing and storing much greater quantities of data, with increasing bandwidth and associated speed of internet transmission making the dissemination of material a more rapid and personal process than previously possible.

The exchange of child pornography has been described as the primary means by which paedophiles misuse the internet (Durkin, 1997). Prior to the internet, paedophiles utilised more clandestine means of circulating material, such as newsletters and sharing copied images by post. Authors have suggested that it is not the availability of child pornography on the internet that has fuelled its use by online child sex offenders, but rather ease of access to a greater variety of material that was only available previously at great financial cost coupled with personal risk (Cohen-Almagor, 2013).

The role of the internet for paedopornographic purposes has been discussed by numerous authors (Krone, 2004; Ferraro and Casey, 2005; UK Government, 2013b), with broad agreement that the internet and its increasing availability has led to an increase in the “range, volume and accessibility of child pornography” (William and Barak, 2001; Krone, 2004). Figures published by CEOP (2013) presented a two fold increase in the number of indecent images of children shared by UK internet users between 2011 and 2012, with a total of 70,000 still and moving images being brought to their attention. The advancement of the internet and associated technologies has seen their misuse by online child sex offenders to “exploit and injure" minors (Durkin, 1997), with an associated increase in the volume of child pornographic images available on the internet. It is suggested that these technological advances have made such material more readily accessible and pervasive (Wolak *et al.*, 2011), with distribution being efficient and to some extent, anonymous (Cohen-Almagor, 2013).

It has been observed that paedophiles utilise the internet for their requirements which can be classified into four groups (Durkin, 1997; Cohen-Almagor, 2013);

1. To access, download and circulate inappropriate images of children
2. To locate victims
3. To solicit children for sexual purposes (grooming)
4. To communicate with other paedophiles

With the rise of the internet, material involving the sexual exploitation of children has progressed from a select number of images circulated and exchanged between paedophiles, to an influx of new material as technology has enabled photographs to be taken easily and uploaded instantaneously and shared worldwide within a matter of minutes (Howitt and Sheldon, 2007).

The internet has been described as an invaluable networking tool, allowing like-minded individuals to congregate in on-line virtual communities. This function of the internet has been described as a "social consolidation mechanism" for paedophiles (Durkin and Bryant, 1995), enabling the sexual desires of paedophiles to be corroborated by others with shared interests (Wolak *et al.*, 2011). This contact network provides a "supportive social context" (Durkin, 1997) which enables paedophiles to disseminate and propagate their ideas and images, and to reinforce their belief that such activity is normal (Cohen-Almagor, 2013). Quayle and Taylor

(2002a) present the case that the presence of large quantities of child pornography online, acts as proof for the offender that their behaviour is not only normal, but is shared by a large collective of others.

The internet has provided a means for paedophiles to contact children without leaving the privacy of their own home. In the real world (as opposed to the internet), the access which paedophiles have to children is limited by opportunity (Quayle and Taylor, 2002a). There are no such limits on the internet, with child pornography in many formats being available at all times. It has been thought that this factor creates a sense of security for the paedophile as they are no longer required to solicit children publicly, but rather can groom potential victims in an environment where the intervention of a guardian is minimal (Quayle and Taylor, 2002b).

Utilising computer networks for the purpose of distributing child pornography is not a new occurrence, with the exchange of such material via "bulletin board systems" being recorded in the United Kingdom as early as 1985 (Ferraro and Casey, 2005). Since the mid 1990s the issue has become more prevalent with advancing technology enabling faster and cheaper means to access the internet (Hoffman *et al.*, 2004), and disseminate material via file sharing systems with widespread internet access now available from the privacy of one's own home (Office of National Statistics, 2012). Figure 2 is a graphical representation of the number of households with internet access from 1998 to 2012 (Office of National Statistics, 2012).

It is this privacy offered by an internet connection at home, combined with the perceived anonymity and associated disinhibition that has been attributed to the exploitation of this technology for deviant and criminal purposes (Jenkins, 2001, Quayle *et al.*, 2006; Aiken *et al.*, 2011). In addition, technological advancement of both imaging and computer equipment has seen the production of child pornography move into the home setting, thus eliminating the need for photographs and/or videos to be commercially processed, with it being suggested that this has increased the levels of abuse as the associated risk of being caught is perceived as lessened (Quayle and Taylor, 2002a).

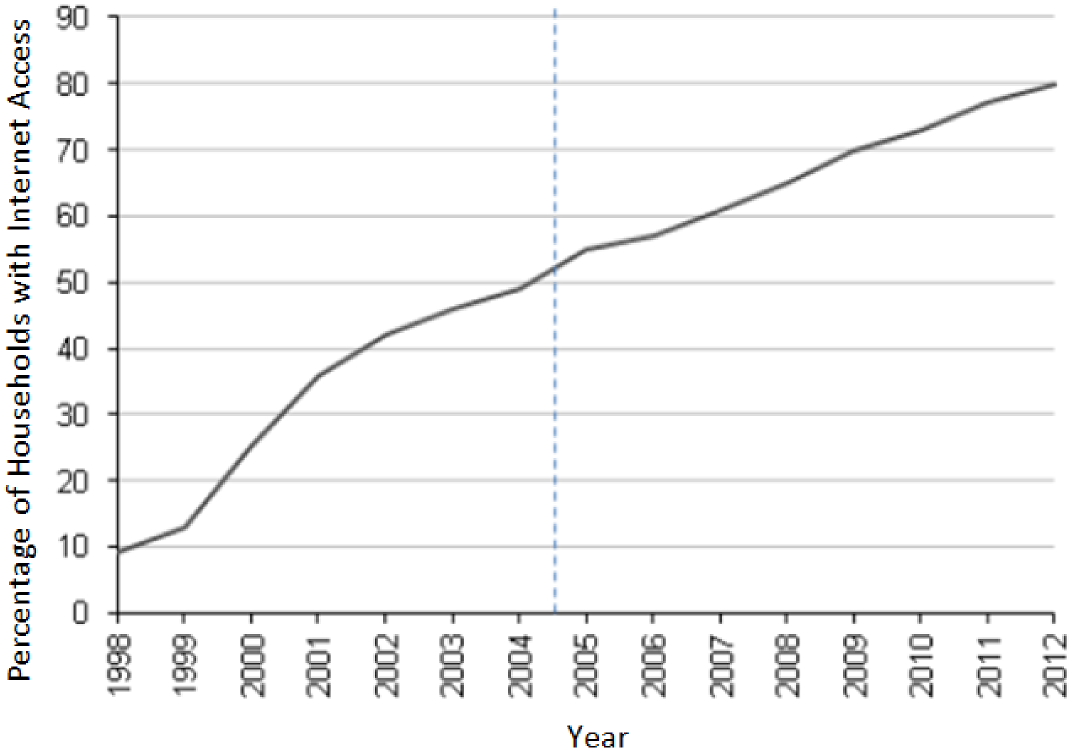


Figure 2. UK households with internet access (taken from Office of National Statistics, 2012)

With the increasing use of the internet for such purposes, police casework now includes a substantial number of investigations relating to indecent images of children being downloaded and disseminated via the internet (Carr, 2003).

Due to the sensitive nature of investigations and criminal proceedings related to the sexual exploitation of children, much effort has been placed on regulating the internet to restrict the dissemination and availability of paedopornographic material (Cohen-Almagor, 2013; Edwards *et al.*, 2013). The Internet Watch Foundation (IWF) was established in 1996, to act as a safety mechanism to "hinder the use of the internet for illegal purposes, and to provide a response mechanism where illegal activity is identified" (Cohen-Almagor, 2013). The IWF was created in conjunction with the online industry, law enforcement agencies, local government, and international partners, with the aim of restricting the availability of illegal content (Internet Watch Foundadtion, 2012) including;

1. Images of child sexual abuse, from both UK and International web sites
2. "Criminally obscene" adult content from the UK
3. Images of child sexual abuse which are non-photographic and hosted in the UK

The UK Parliament approached Internet Service Providers (ISPs) in 2013, to request that they take further steps to filter explicit content on public Wi-Fi networks. Subsequent discussions between the government and ISPs have resulted in agreements that filters be in place which will automatically block all pornography (Ashford, 2013; BBC Politics, 2013; Kiss, 2013). Any internet users wishing to view pornography of any kind will have to "opt in" to be able to access such content (Ashford, 2013; Williams and Leather, 2013).

Search engines such as Google® and Microsoft® have also implemented measures to filter child pornography and associated illegal content from search results (Cuthbertson, 2013). The "auto fill" feature is disabled when it is recognised that a search may be for child pornography, and warning messages are displayed when any such searches are conducted (Dixon, 2013). The warning image displayed by

Google® is accompanied by a link from which child abuse images can be reported, or help can be sought. Figures 3 and 4 show both the warning message and associated links respectively.

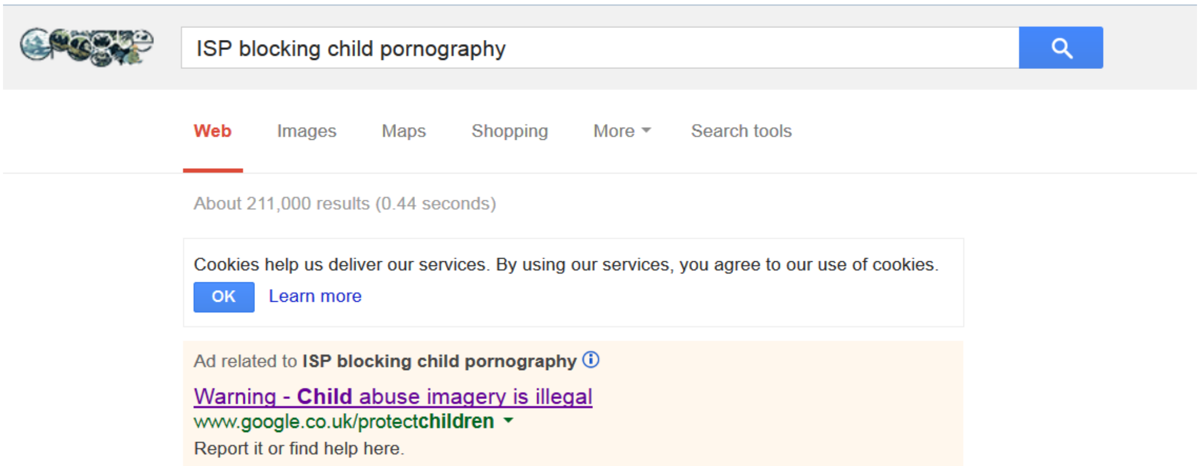


Figure 3. Warning message displayed when searching for terms related to child pornography

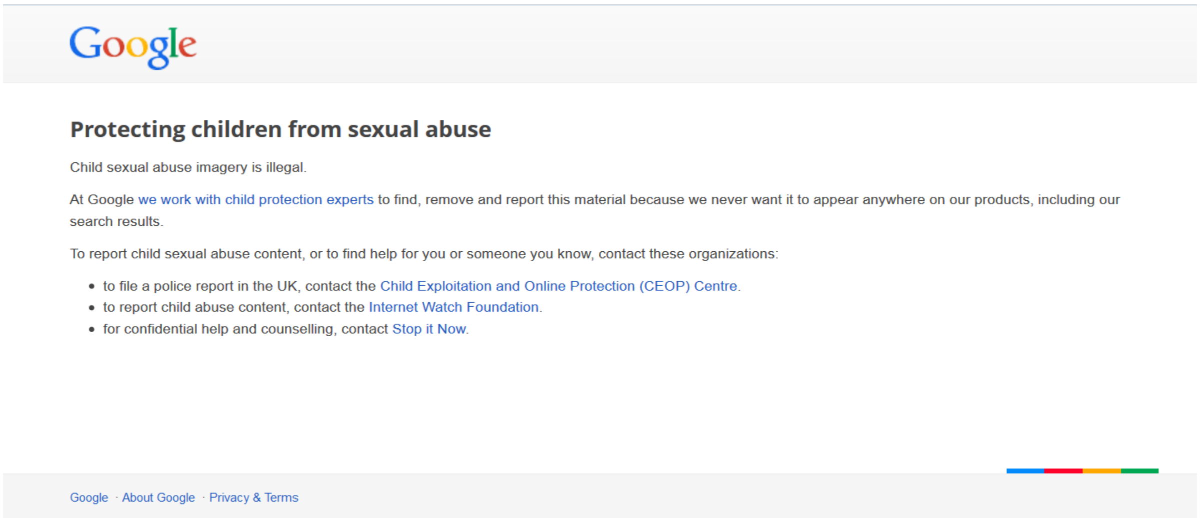


Figure 4. Links associated with Google® warning message

The requirement for regulation can also be demonstrated with regards to individuals placed on the Sex Offender's register, as they are restricted from accessing the internet, prevented from owning any device which can access the internet, or possessing image taking devices (Blaisdell, 2008; Brant, 2008; McCartan and McAlister, 2012). The very nature of the internet as a network of global communication, operating out with the bounds of a single legal jurisdiction means that its governance and regulation cannot be readily overseen by a single body or organization (Jenkins, 2001). As such, it has been commented that internet child pornography can only be governed via a pluralistic approach with a collective response from both national and international authorities (Taylor, 2003; Akdeniz, 2008).

The increasing number of digital images being presented in cases of child exploitation is reflected in the increased caseloads of experts in forensic human identification, with law enforcement agencies recognising the utility of this skill set in suspect and offender comparisons (CEOP, 2013). It is for this reason that research such as this project is being conducted.

5. Related Cases

Experts in forensic human identification have been involved in assigning identity to numerous victims of crimes, traditionally those which have resulted in the death of the victim (Cattaneo, 2007; Dirkmaat *et al.*, 2008). As the remit of the forensic anthropologist has changed in recent years to include the assignment of biological parameters to living individuals, law enforcement officers have recognised the utility of such a skill set in cases requiring suspect and offender comparison based on biological traits (İşcan, 2001; Cattaneo, 2007). When presented with images of child sexual exploitation, the aim of the forensic analyst is to assign identity to the individual(s) appearing therein. As the remit of the forensic anthropologist is to assign identity to individuals based upon biological parameters (Dirkmaat *et al.*, 2008), the identification of offenders in images relating to cases of child exploitation is based upon the analysis of observed anatomical features. The analysis of anatomical features to assign identity falls within the remit of biometrics, which will be discussed later in this document.

Vein pattern analysis for the purposes of suspect-offender comparison was first introduced to the UK judicial arena in late 2007. The first case of this kind saw Professor Sue Black working in conjunction with the National Police Improvements Agency (NPIA), to assist in identifying an offender based upon the physical features observed in an image of the forearm. The image was part of an investigation relating to child abuse, where the victim had set up an IR recording device to capture evidence of the ongoing sexual abuse. In this instance, only the forearm of the offender was visible in the captured video, with the singularly visible distinguishing feature being the vein pattern due to the video being captured in IR. The assistance of

Professor Black was sought to analyse the presence or absence of correlating features between the forearms of the suspect and offender. Despite vein pattern analysis previously being confined to the arena of biometric security, this method was deemed admissible by the judge for the purpose of forensic human identification due to its foundation in the classical discipline of human anatomical variation.

Since the introduction of vein pattern analysis to the UK courts as a means of suspect-offender comparison, experts at CAHId have been approached to consult on numerous related cases. A selection of these cases is listed below. To date, this technique has mainly been utilised in cases of sexual abuse (primarily that of children). This may be due in part to the nature of cases involving sexual exploitation, where the offender captures images of the abuse as trophies (Goode, 2010). Offenders take great care to conceal any traditional indicators of their identity (such as their face), however their hands are often present in the pictures as they are interfering with the child (Lanning, 1992).

As the remit of this research focuses on vein pattern analysis in the dorsum of the hand, it is only the cases in which this anatomical area has been utilised which are presented. Please note that some of these cases remain active and therefore have been anonymised.

R v. Mr C – 2009

Experts of the Centre of Anatomy and Human Identification (CAHId) of the University of Dundee were approached by West Yorkshire Police for assistance in assigning the identity to an offender whose hands were visible in images of child sexual exploitation.

From a mobile phone belonging to the suspect, 37 stills were captured from video files. These 37 images depicted the hands of the offender abusing the victim. Five still images of the suspect which were captured using a digital camera in the custody suite were presented to the experts for comparison analysis.

Comparison of suspect and offender images highlighted similarities between the physical features observed in the right hand of the offender, and the right hand of the suspect. As such, it could not be ruled out that the suspect and offender were one and the same. When presented with this evidence, the suspect changed his plea to guilty and was sentenced to a 2 year term of incarceration.

Operation Satchel - 2011

Following the success of the 2009 case against Mr C, West Yorkshire Police again requested the assistance of CAHId staff in analysing images related to a case of child sexual exploitation. A single offender image was retrieved from a mobile phone video depicting the sexual abuse of a child. CAHId staff were provided with 26 images of the hands of the suspect in custody, again taken with a digital camera in the custody suite. The resultant analysis report demonstrated numerous points of comparison in the physical features of the offender and the left hand of the suspect.

At the time of writing this case is ongoing.

Operation Malta - 2011

Central Scotland Police presented CAHId experts with a video captured using a digital camera and 4 still images depicting images of child sexual exploitation. In contrast to previous cases, comparison was not conducted with images captured in the custody suite, but rather images of the suspect contained on the same camera as the child pornography. 6 still images where retrieved from the camera for comparison purposes, which depicted the suspect with both his hands and face visible. Analysis indicated similarities between the vein pattern in the left hand of the suspect and the corresponding hand of the offender.

When presented with the results of analysis of the two sets of images, the suspect entered a plea of guilty and was sentenced to 4 years imprisonment with lifetime inclusion on the Sex Offenders Register. This was the first successful case based solely upon vein pattern analysis of the dorsum of the hand.

R v. TC – 2011

11 offender images from a batch of 21 movie clips and 508 stills taken using a mobile phone were submitted for analysis by the Metropolitan Police. Suspect images were again existing photos in series on the same imaging device. Analysis of both the right and left hands of the suspect and offender, presented numerous points of similarity, resulting in the suspect pleading guilty despite previously protesting innocence. A sentence of 6 years was passed to the offender.

R v. TR – 2011

In contrast to cases outlined previously, R v. TR involved 119 offender images associated with a case of adult rape. Comparison analysis was conducted with 28 suspect images obtained by investigators in the custody suite. The left hand and forearm of the suspect and offender were in possession of correlating features. Based upon the evidence presented, a jury found the defendant guilty, and he was sentenced to a term of 4 years by the Procurator Fiscal.

R v. CT – 2012

In this ongoing case, Strathclyde Police required the analysis of a mobile phone video showing the right hand of the offender, and 14 associated still images depicting both hands.

Operation Pebblebrook - 2012

In this case brought by Merseyside Police, 23 still images from a camera required analysis. 4 suspect images obtained from 2 suspects during interview in police custody were demonstrated to be similar to the left hand of the female offender, and right hand of the male offender. Both the accused changed their pleas to guilty and are currently awaiting sentencing.

R v. RH- 2013

Suspect and offender comparison was conducted using 5 offender images retrieved from a mobile telephone, and 40 suspect images from the same device. Analysis concluded that there were significant similarities between physical features of the right hand of the suspect and that of the offender. This analysis forms part of an ongoing case being conducted by Staffordshire Police.

From the case examples provided above, it is evident that numerous imaging devices are utilised by offenders to capture pictorial evidence of the sexual abuse enacted by them. The method upon which current vein pattern analysis for use in forensic investigation is based, was created utilising images captured using a DSLR camera in both visible and infra-red light settings (Meadows, 2011). This research aims to assess any variation with which veins can be visualised using both a digital camera (DSLR) fitted with an infra-red (IR) filter (considered to be the gold standard), and a VeinViewer (essentially a webcam with IR capabilities), to determine if the VeinViewer may be used as a novel technical alternative for use in vein pattern analysis.

6. Evidential Admissibility and Novel Scientific Evidence

Vein Pattern Recognition has previously been deemed admissible in the UK courts, with the current research being undertaken to further develop analytical methodology and to provide a reference data set from which the robustness of results can be determined.

This chapter will explore the relationship between Science and Law, with a discussion of the admissibility requirements of novel scientific evidence.

6.1. Forensic Science in Court

An intrinsic link is apparent between the disciplines of forensic science and law, with the term forensic meaning "pertaining to the court of law" when its Latin origin is explored (Pyrek, 2010). The relationship between law and science is increasingly noted as they seek solutions to expanding criminality bred by advancing technologies through the application of emerging science to identify criminals (Raitt, 2014). Forensic science has been acknowledged as a valuable tool in legal proceedings, being hailed as a "vital instrument for the detection of crime and the administration of justice" (UK Government, 2005a).

The basic premise of a trial is to establish matters of truth and fact based upon the evidence presented (Haack, 2008). In the setting of a Courtroom, forensic science is viewed as a mechanism by which some degree of certainty in the guilt or innocence of an accused party is determined (Pyrek, 2010). The different principles of law and science become apparent in the Courtroom, with scientists providing likelihood ratios supported by data to present the court with an interpretation of the evidence, and legal professionals demanding succinct and definitive statements (Berger and Solan, 2008).

When presented in the Courtroom, forensic scientific evidence can take the form of factual technical evidence (for example reports and exhibits), expert witness evidence, or a combination of the two (UK Government, 2005b). Prior to its inclusion at trial, the forensic scientific evidence in question must be deemed admissible by the court with regards to the case in question (Pyrek, 2010).

6.2. Admissibility of Novel Scientific Evidence

Whilst many scientific truths are widely accepted by both the scientific and legal communities (Berger and Solan, 2008), new or "novel" science being presented in court must first be deemed admissible prior to its inclusion at trail (Shelton, 2011; Ward, 2013). It is the duty of the presiding Judge to determine if the forensic evidence being presented for consideration is scientifically sound and appropriate in relation to the case in question (Pyrek, 2010; Shelton, 2011; Ward, 2013). This novel scientific evidence is delivered by an expert witness capable of "furnishing the court with information which is likely to be outside the experience or knowledge of the judge or jury" (Dempsey, 2004; Health and Safety Executive, 2013). Simply, it is the role of the expert witness to assist the court in understanding and interpreting evidence with which they are unfamiliar.

Separating expert witnesses from other witnesses is their allowance to provide testimony based on their learned opinion which non-experts are not permitted to do (Crown Prosecution Service, 2010; Mallett, 2014). The assignment of expert status to a witness is determined by a broad set of criteria which include; the length of time which they have been practitioners in their field, qualifications attained, experience in related cases, publications of work undertaken and recognition by peers (Mallett, 2014). Whilst these criteria are subject to general acceptance in the United Kingdom, the requirements of an expert witness in the United States are dictated by Federal Rule of Evidence 702 (United States Supreme Court, 2010; Shelton, 2011). Federal Rule of Evidence 702 defines an expert witness as an individual qualified to present the court with testimony based upon their opinions on a subject matter on which they have acquired expertise through knowledge, training, skill and experience (Hutchinson, 2012). Whilst there is no definitive list of required criteria to define an expert witness, the independence and limitations to the remit of the expert witness are legally defined in the UK under the Civil Procedure Rules (Ministry of Justice, 2014).

Admissibility criteria are requirements stipulated by the court which must be fulfilled by the novel scientific technique in question prior to its inclusion at trial (Simard and Young, 1993; Shelton, 2011). In the United Kingdom, requirements for admissibility of novel scientific evidence have been the subject of significant discussion and debate, with commentators backing a standardized approach as is present in the United States (Ward, 2013).

To comprehend the basis of admissibility decisions in the UK, the determining principles as adopted by the United States legal system will be explored.

6.2.1. Admissibility in the United States

The admissibility of evidence in the legal arena of the United States is considered according to four landmark cases; Frye vs. United States 1923, Daubert vs. Merrell Dow Pharmaceuticals, Inc. 1993, General Electric Co. vs. Joiner 1997, and Carmichael vs. Kumho Tire Company Ltd. 1999. Each case will be discussed in turn with an emphasis on how their rulings affected admissibility criteria.

<u>Frye vs. United States, 293 F. 1013 (1923)</u>

The case of Frye vs. United States (1923) required the presiding judge "to determine the standard for admitting expert scientific testimony in a federal trial" and defined the first step of the United States legal system to develop admissibility criteria (Mallett, 2014). This general rule of acceptance for determining the admissibility of scientific evidence become known as the Frye Standard (Redmayne, 2001; Mallett, 2014).

The issue in contention in the case of Frye vs. United States was the inclusion of polygraph test evidence which was later discounted due to its associated lack of reliable scientific foundation. The resultant ruling decreed that for expert testimony to be deemed admissible, the science on which said testimony is based must be sufficiently reliable and accepted, lending to the Frye Standard of evidential admissibility. The premise of this standard placed responsibility on the courts to determine the reliability of novel scientific evidence based upon general acceptance by peers, examination of related literature and legal precedence (Hamilton, 1998). The exponential development of technology in the following 50 years from establishment of the Frye Standard of general acceptance, saw numerous technological advances slip into general acceptance without having undergone careful examination due to their familiarity (e.g. the telephone) (Hamilton, 1998). It was soon acknowledge that general acceptance of science without an in-depth understanding of the underlying principles would result in the inclusion of "junk science" which would in turn undermine the judicial process (Hamilton, 1998; Shelton, 2011).

A lack of uniform adoption of the Frye Standard across the states resulted in the dismissal of the general acceptance rule and the enactment of the Federal Rules of Evidence in 1975, which stipulated that the testimony of a qualified expert be considered admissible if relevant to the case at hand (Haack, 2005). These rules of evidence govern the admission of facts in both civil and criminal cases of the federal courts of the United States, overturning the Frye Standard (Spitaletto, 1994).

<u>Daubert vs. Merrell Dow Pharmaceuticals, Ltd., 509 U.S. 579 (1993)</u>

Daubert vs. Merrell Dow Pharmaceuticals Ltd. was a lawsuit seeking damages against Merell Dow, the pharmaceutical company responsible for the manufacture of Benedictin anti-nausea drugs, which were routinely given to pregnant women to alleviate morning sickness, as it was claimed that these drugs caused birth defects (United States Supreme Court, 2010). This case is of note as the original Frye Standard was effectively abandoned, with the presentation of a new series of criteria by which the admissibility of novel scientific testimony be determined by the judge, being presented (Hutchinson, 2012).

The result of the Daubert ruling led to the courts clarifying the remit of the trial judge in assessing scientific knowledge and its subsequent admission. The ruling emphasised that the reliable scientific foundation of presented evidence be ensured prior to admission as evidence, combined with an assessment of relevance to the case at hand (Cheng and Yoon, 2005). The presiding judge in the case, Justice Blackmun, presented general observations that should be henceforth taken into consideration during the preliminary assessment of the suitability of evidence;

1. Testing – assessment of the basic underlying principles upon which the scientific technique is based
2. Peer Review and Publication – critical scientific scrutiny of the reliability of the underlying theory and technique by peers
3. Rate of Error – utilised to determine the reliability of the technique to produce consistent results
4. General Acceptance – acting as an indication of the weight of reliability of a principle

<u>General Electric Co. vs. Joiner, 522 U.S. 136 (1997)</u>

The ruling of this case acted to extend the gatekeeping role of the judge in determining the admissibility of novel scientific evidence as outlined by the Daubert factors (Haack, 2008). The plaintiff sought damages as it was claimed that exposure to PCBs in the workplace had promoted single-cell lung cancer. An expert testifying on behalf of Joiner opined that exposure to PCBs was likely to have caused his cancer. As no definitive link between PCBs and small-cell lung cancer was presented, the testimony of the expert was deemed inadmissible due to a large analytical gap between the presented evidence and the opinion of the expert (Grudzinskas and Appelbaum, 1998; Christensen and Crowder, 2009). In relation to admissibility criteria, the outcome of Joiner concluded that it was the role of the presiding judge to scrutinise the methods utilised by the expert and the analytical reasoning employed to deduce their testimony. The undertaking of this additional scrutiny prior to admission was enacted to eliminate expert testimony which was derived from tenuous links to the scientific principle in question (Berger and Solan, 2008; Mallett, 2014).

<u>Kumho Tire Co. Ltd vs. Carmichael, 526 U.S. 137, 119 S (1999)</u>

This Supreme Court ruling clarified the application of Daubert criteria to expert testimony from non-scientific disciplines, declaring the gatekeeping role of the judge should be exercised in relation to the testimony of all expert witnesses regardless of their field of expertise. As with previous admissibility criteria discussed under the Daubert ruling, to be admitted as evidence, the reliability and relevance of the evidence must first be established prior to admission. This ruling confirmed the authority of the judge in matters of admissibility.

6.2.1.1. Amendments to Federal Rule of Evidence 702

The state system presented within the United States has resulted in the outcome of the aforementioned rulings not being uniformly adopted (Mallett, 2014). As a result of this lack of uniform adoption, Federal Rule of Evidence 702 has undergone several amendments in a bid to reduce any ambiguity arising from the application of these outcomes (Federal Evidence Review, 2014). These amendments have incorporated the principles of Daubert and the subsequent rulings of Joiner and Carmichael to stipulate that the testimony of an expert witness be deemed admissible when;

1. The specialised knowledge of the expert acts to assist the jury to understand the evidence at hand
2. The expert testimony is based upon sufficient data or facts
3. The expert testimony is the product of reliable principles and methods
4. These principles and methods have been reliably applied by the expert

This simplification of admissibility criteria is attempting to encourage their state-wide adoption with the aim of increasing the accountability and constancy of expert witness testimony (Federal Evidence Review, 2014).

6.2.1.2. The National Academy of Sciences (NAS) Report (2009)

Individuals representing the National Academy of Sciences, the National Academy of Engineering and the Institute of Medicine were approached to form a committee to investigate the needs of the forensic science community. The resultant report of this committee entitled “Strengthening forensic science in the United States: A path forward” highlighted serious issues of concern with regards to research and practice in the forensic science arena (National Research Council, 2009a). The report concluded that a concerted national effort was required to address the issues highlighted to ensure the integrity of forensic scientific disciplines (National Research Council, 2009a).

Recommendations for improvement included; the creation of a National Institute of Forensic Sciences (NIFS), the standardization of reporting practices and associated terminology, and mandatory accreditation (National Research Council, 2009b). The separation of forensic science practitioners from law enforcement agencies via the creation of NIFS was recommended to ensure that both research and results are conducted and obtained in a natural environment, free from any bias which may result from the pressures placed upon scientists by their employers. In addition, support for research into observer bias and error rates was promoted, with a standardization of terminology and reporting practices championed to enable cohesion of research conducted in related areas (National Research Council, 2009b). A primary recommendation of the NAS report (2009) stipulated the requirement for compulsory accreditation of all forensic laboratories and certification of practitioners as a means by which the competency and proficiency of experts and their methodologies could be governed.

The admission of and reliance upon forensic evidence in criminal trials were highlighted as important issues by the NAS report (2009). The extent to which a particular forensic discipline is founded upon methodology which is considered both robust and reliable dictates the capacity of accurate analysis. In disciplines which are largely reliant upon human interpretation of results, concern was expressed regarding the possibility of human error and observer bias, inherently amplified by a lack of robust operational procedures and standards of performance. Such concerns greatly impact upon the utility of forensic evidence which has been admitted to the court, with the allowance of such evidence having far reaching implication such as miscarriages of justice and ruling based upon flawed evidence (National Research Council, 2009a; National Research Council, 2009b).

The findings of this report have received mixed reactions, with some states taking immediate action to remedy the highlighted concerns by implementing the recommendations of the committee, whilst others are of the opinion that the present system is indeed adequate continuing to adhere to the same guiding principles as before.

6.2.2. Admissibility in the United Kingdom

The House of Commons Science and Technology Committee had reported on the state of forensic science provisions in the UK (UK Government, 2005a) prior to the publication of the NAS report (2009). The outcome of this report entitled "Forensic Science on Trial" was the establishment of a Forensic Science Advisory Council "to oversee the regulation of the forensic science market and provide independent and impartial advice on forensic science" within the United Kingdom (UK Government, 2005b).

Mirroring the issues of uniform admissibility criteria in the US, Forensic Science on Trial raised concerns that an absence of defined protocol for the validation of scientific techniques prior to their admittance in court undermined and weakened the judicial process by enabling inadequate forensic evidence to be utilised at trial. This absence of protocol was accredited to the lack of "gatekeeping duties" exercised by UK judges who were deemed unable to determine the validity of scientific evidence in the absence of input from scientists themselves (UK Government, 2005a). The newly formed Forensic Science Advisory Council was tasked with developing a "gate-keeping" test to scrutinise expert evidence in order to assess its admissibility.

This test was based upon the Daubert principles and developed with input from judges, scientists and other individuals involved in the criminal justice system.

The Law Commission of England and Wales published a consultation paper in 2009, supporting the work of the House of Commons Science and Technology Committee, by recommending the adoption of reliability based admissibility criteria echoing that of Daubert (Law Commission, 2009).

The objective of such criteria was to exclude unreliable expert testimony, by only admitting expert opinion for consideration by the court after it has undergone scrutiny and was deemed to be sufficiently reliable (Law Commission, 2009). The Law Commission report closely echoed that of the House of Commons Science and Technology Committee, by warning of the implications of flawed expert witness evidence, which may lead juries to base their conclusions on unreliable evidence, leading in turn to miscarriages of justice and a loss of public confidence in the criminal justice system (Law Commission, 2009).

The draft Criminal Evidence (Experts) Bill published with the resultant report provided the admissibility criteria that should henceforth be applied to exclude unreliable expert evidence (Law Commission, 2011). The bill recognises that such criteria do not need to be applied "routinely or unnecessarily", but should be applied in appropriate cases, with guidance provided for judges on when and how to apply the test criteria (Law Commission, 2011). As with the US system, these recommendations require the judge to fulfil a gatekeeping role.

The Bill acted to codify admissibility requirements, procedural rules and provisions in an attempt to establish an effective framework for screening expert evidence during the pre-trail stages. The recommendations of the report and requirements of the resultant Bill also sought to encourage higher standards amongst expert witnesses which in turn will result in reliable and accurate expert evidence being presented in court (Law Commission, 2011).

Whilst the Law Commission report (2009) and Criminal Evidence (Experts) Bill (2011) moved to enact law reform in England and Wales, their recommendations were not adopted into Scottish Law. The Scottish Universities Insight Institute commenced a consultation series in April 2011 to address the admissibility of scientific evidence in criminal trials in Scotland (Scottish Universities Insight Institute, 2011). As with findings of the Law Commission Report, issues for further consideration included the standards of reliability for legally admissible evidence, with a focus on new emerging (novel) scientific techniques for example digital photographic evidence utilised for human identification purposes (Scottish Universities Insight Institute, 2011). With the same issues of standardized reliability tests being raised by subsequent consultation bodies, it is hoped that continuing collaboration between experts and individuals involved in all levels of the judicial process will result in recommendations to be implemented to regulate the accuracy, reliability and validity of forensic scientific evidence.

The importance of reliable forensic science in the UK is exemplified by the specialist role of the Forensic Science Regulator who works as an independent advisor to the government, to address issues pertaining to quality and standards of forensic science in the UK. Since appointment to office, the Forensic Regulator has introduced, new models of regulation and accreditation for forensic science practitioners based upon those in place for other organisations operating under International Standards Organization for Standardization guidelines. Such guidelines have been introduced by the Forensic Regulator with the aim of raising both organisational and personal accountability and competence (Forensic Science Regulator, 2013). It is hoped that with such accountability, new scientific techniques will not be viewed with scepticism by the courts as both the scientist and their science will be regulated and accredited, leading to the accommodation of novel scientific evidence without foregoing reliability (UK Government, 2013).

With the implementation of these recommendations, novel scientific evidence can be accommodated in the legal arena, with the admissibility of new techniques being easily discernable due to the solid foundation of accurate and reliable science dictated by the new framework of accreditation and accountability. Such safeguards assist in admitting the presentation of reliable expert testimony at trail as judges no longer require in-depth understanding of the basis of the science presented, but rather an understanding of the error rates and bias of potential statistics which must now accompany scientific evidence.

Whilst Vein Pattern Recognition has previously been deemed admissible in the UK courts, it is the objective of this study to provide information regarding the utility of VeinViewer images for human identification based upon VPR. As previous admissibility has been based upon VPR utilising digital images captured using standard photographic methods, this work is being undertaken to provide detailed analysis of the accuracy and reliability of VPR based upon a novel image capturing device (the VeinViewer), with a view to introducing this recording method in the custody suite should it be found to outperform traditional DSLR images in VPR.

7. Biometrics: An Introduction

Biometry, the science of biometrics, is defined by the Oxford English dictionary as "the application of statistical analysis to biological data" (Oxford English Dictionary, 2014). Therefore the science of biometrics is by definition the investigation of the identification of an individual based upon inherent physiological/anatomical or behavioural features which can be quantified (Golfarelli *et al.*, 1997; Wang and Leedham, 2005). Physical features employed for biometric identification include fingerprints, facial geometry, retina patterns, hand geometry and vein patterns. Signatures and vocal patterns have been employed for behavioural based biometric systems (Wang and Leedham, 2005). In essence, biometric systems are based upon pattern recognition of behavioural and physiological traits (Bhattacharyya *et al.*, 2010).

Jain *et al.* (2011) list the essential criteria for a successful biometric system;

1. Universality: each individual should possess the trait which is to be measured
2. Uniqueness: the trait should be sufficiently different between individuals
3. Permanence: the trait is required to be stable over a period of time
4. Measurability: the characteristic in question should be able to be measured quantitatively
5. Performance: the accuracy with which identification can be achieved
6. Acceptability: the extent to which end users are accepting of the biometric system
7. Circumvention: the security of the system against fraudulent use

These identified factors can be utilised to determine the suitability of a physiological or behavioural feature for use on biometric application.

7.1. History of Biometrics

The lineage of biometrics can be traced back millennia, with fingerprints being utilised as signatures to assign origin to clay products and to agree upon business transactions (Cole, 2001). Physical measurements of the human body (the practice of anthropometry) have been utilised for centuries as a means of classification and identification (Pugliese, 2010). The fundamental basis of modern biometric technologies prevalent in today's society can be attributed to these early methods, and so they will be discussed briefly.

7.1.1. Anthropometry

Anthropometry utilises physical measurements of the human body to identify an individual (Joseph, 2001). The most famous anthropometric system was that created by Alphonse Bertillon, which recorded physical measurements of individuals with accompanying descriptions recorded in a standardised manner, leading to the Bertillon system being recognised as the first system of criminal identification of the modern age (Fosdick, 1915). The Bertillon system evolved in the late nineteenth century in Europe as a means to address the increasing social menace of repeat offenders, with the system being implemented globally by police forces to address the same issue (Gridack, 2009). The aim of this system was to assign identity accurately to any individual taken into custody by Parisian law enforcers. Although recognised as an anthropometric system, Bertillonage also included photographs and written physical descriptions of offenders. The ability to assign identity assisted in providing adequate punishment, as case files relating to previous misdemeanours could be retrieved, with harsher punishments being prescribed for repeat offenders (Cole, 2001). Prior to the introduction of Bertillonage, identification of known criminals was reliant upon the memory of serving police officers, photographs and alphabetised registers.

7.1.2. Fingerprinting

Whilst it is not possible to determine exactly when fingerprints were first utilised as a means of authenticating personal identity, historians have charted the use of fingerprints as signatures and seals dating from Babylonian times (500 B.C.) and dynastic China (202 B.C.-220 A.D.). These uses of fingerprints suggest that their uniqueness was recognised by these early civilisations. Classification of fingerprints according to observed feature types was first carried out by Purkyně in 1823, with Galton continuing classification in his 1892 works, by identifying the three primary feature types still utilised in finger print analysis today; loops, whorls and arcs (Stigler, 1995). It must be noted however that the uniqueness of fingerprints was not described in European literature until the late seventeenth century (Caplan, 1990), when the field of microscopy was becoming increasingly prevalent and numerous authors noted that no two individuals possessed the same pattern of papillary ridges (Cole, 2004). As employed by Bertillon, an indexing system of fingerprints was created to verify the identity of individuals, with a successive catalogue and classification system produced to identify an individual.

As with these two early systems, the most effective biometric technologies are those which arise to solve the contextual problems of the era (Pugliese, 2010). Recent decades have seen extensive studies conducted on the utility of various physical features for biometric purposes, the vast majority of which are associated with access and security (Vacca, 2007; Jain *et al.*, 2011). A review of the associated literature highlights fingerprints, facial recognition and iris pattern recognition as main research areas (Vacca, 2007; Bhatia, 2013; Bowyer *et al.*, 2013; Khalil *et al.*, 2013). More recently, research interest has focussed on vein pattern biometrics of the hand, with application already seen in computer security, homeland security and access control (Wang and Leedham, 2005). This widespread employment is testament to rapid growth of vascular pattern technology (Du and Swamy, 2014; Sharma *et al.*, 2014).

7.2. Biometric Systems

Biometric systems in essence are implemented to perform either identity verification, or identity recognition (Golfarelli *et al.*, 1997). Identity verification requires the user to be verified to lay claim to an identity. Biometric systems based on identity verification are in essence two-step processes; firstly an identifier is presented to the system to recall the biometric template associated to said person, with the second step requiring the user to present their own biometric for comparison. This is in essence one-to-one matching and is also referred to in the literature as "positive identification". Identity recognition systems must perform a one-to-many match, where the biometric presented for analysis must be compared to the entire database of biometric templates. The process of identity recognition is often categorized as "negative identification"(Wayman, 2002; Wayman *et al.*, 2005).

These tasks are designed to test the two following hypotheses respectively; that the individual presenting biometric information for analysis is an individual known to the system (i.e. the biometric information can be matched to a template already enrolled on the system) or that the submitted biometric belongs to an individual who is not known (enrolled in) the system (Wayman, 2002).

Positive identification relies upon enrolled templates of biometric data, accepting a user's claim to identity if the presented biometric matches an enrolled template. If no match is found, then the claimed identity is rejected. This type of identification requires a one-to-one match and involves a possessed identifier such as an identity card. To operate the system, the user presents their identity card which is associated with an index biometric template. Once the card is read, the template is recalled by the system, and the user is requested to present the same biometric for comparison to be conducted. A duplicate of an enrolled biometric must be presented to circumvent a positive identification system (Wayman *et al.*, 2005). This impersonation of an enrolled user to bypass positive identification is called biometric spoofing (Prabhakar *et al.*, 2003).

In biometric systems employed to undertake negative identification analysis, the presented biometric is compared to all enrolled templates. When a match is found, access is denied. An example of negative identification can be found at border controls, where the fingerprints of an individual are presented for comparison with fingerprint databases of known criminals. To bypass negative identification, a sample must be presented which has been altered from that previously enrolled by the system (Wayman *et al.*, 2005).

With emerging technologies utilising a combination of algorithms for biometric systems, the previous distinctions can no longer be applied puritanically to describe the basis of all biometric technologies. For example, modern surveillance techniques often employ "few-to-many" computational models.

7.2.1. Components of a Biometric System

Typical biometric systems consist of five separate components (Jain *et al.*, 2008). These components are;

1. Sensory Module
2. Feature Extraction
3. Database of templates
4. Matching module
5. Decision module modules.

The number of components utilised is dependent upon the process being undertaken (Wayman, 1997); for example, during enrolment of an individual in a biometric system, only the first 3 identified modules are utilised (Figure 5).

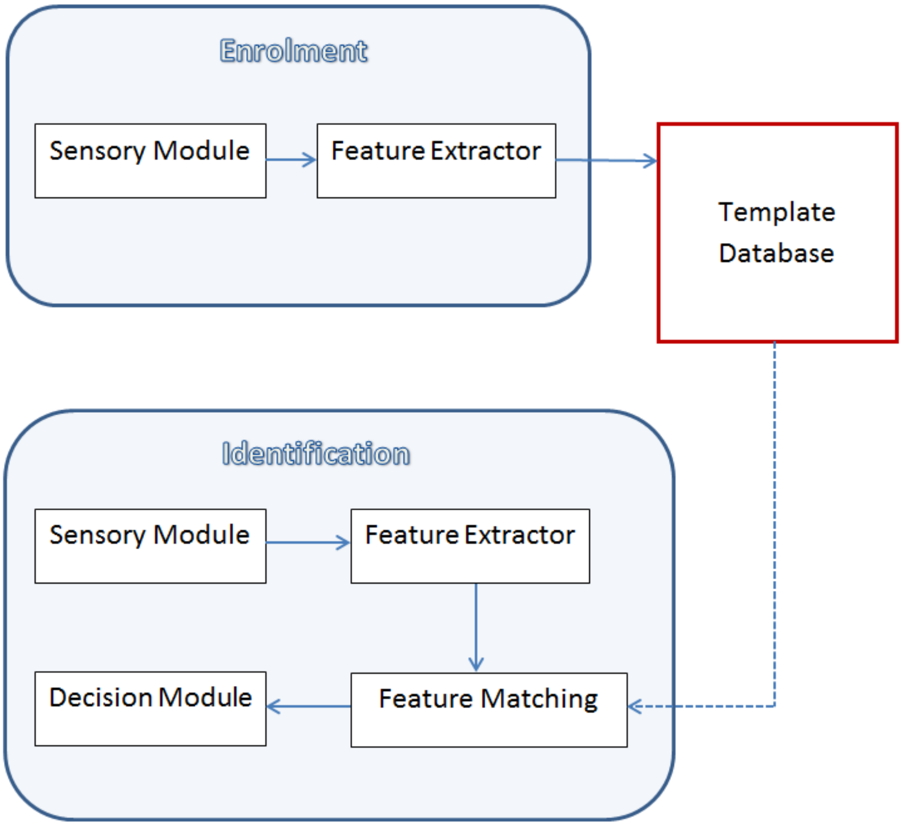


Figure 5. The components of a biometric system utilised in Enrolment and Identification (Jain et al., 2000)

Enrolment is the process whereby a user initially submits a biometric sample to a biometric system for future use. The submitted sample is captured by the sensory module and analysed to extract the relevant features. These features are then stored in template format on a database (Ross and Jain, 2003).

When the user returns to the system requiring their identification to be assessed, again the sensory module and feature extractor are employed for the above purposes. Once the required feature has been extracted from the presented sample, the feature matching module compares the extracted feature from the presented sample to those stored in the template database. The role of the decision module is to determine if the transaction should proceed (in cases were the presented biometric matches that on file) or if access will be denied (if there is no match found) (Matyáš and Říha, 2002).

7.2.2. Effective Biometric Systems

A successful biometric system is one which will identify an individual correctly through comparison with previously enrolled templates of the biometric which is being measured. To assess the effectiveness of a biometric system, system administrators calculate the functioning of the system according to five criteria; false rejection rate, false acceptance rate, throughput rate, user acceptance and financial viability (Daugman, 2000; Phillips *et al.*, 2000; Mansfield and Wayman, 2002; Wayman, 2002).

The false rejection rate (FRR) is a measure of the probability that a match for a genuine user will be not be found in the previously enrolled biometric template. In other words, the claimed identity of a genuine user will be falsely rejected by the system. In terms of user friendliness, a high false rejection rate will cause inconvenience for the user and may in the long run alienate the user from the technology (Golfarelli *et al.*, 1997; Mansfield and Wayman, 2002). The FRR is often referred to as Type I error in the literature (Holmes *et al.*, 1991).

The false acceptance rate (FAR), also known as Type II error, is the probability associated with a false claim of identity being accepted by the system (Holmes *et al.*, 1991). A low FAR is essential to ensure the integrity of the system by preventing fraudulent access (Liu and Silverman, 2001). The FAR can be summarised as the probability that an imposter will be accepted by the system.

The system throughput rate measures the processing capacity of the biometric system. In other words, the number of users that can be processed through the system in a defined period of time is measured. When utilised in high traffic areas, biometric systems must have a processing capacity adequate to accommodate all users without unnecessary delays (Wayman *et al.*, 2005).

User acceptance of a biometric technology is reliant upon many factors. The primary concern of many users is hygiene. This is particularly important when biometric technologies are employed in “dirty” environments, for example hand vein scanners requiring the user to place their hand on a scanner pad have been widely replaced by new “contactless” models. In addition, the “packaging” of the biometric device has been observed to influence user acceptance. This is reflected in the increasing importance placed upon user friendly design. If the user finds the system difficult to use, or finds the process uncomfortable, the system will not be widely accepted (Liu and Silverman, 2001; Mansfield and Wayman, 2002).

Biometric systems are utilised as an efficient means of verifying identity. The processing power of the system must be greater than that of a human carrying out the same function. With verification being conducted expediently and efficiently in a manner which is agreeable to the user, biometric systems can indeed be more time and cost effective. In order to fulfil this criteria, biometric systems must have a low FRR, a low FAR and a throughput rate sufficient for purpose (Prabhakar *et al.*, 2003).

7.3. Biometrics for Security Purposes

Security issues have become prevalent in daily life following the terrorist attacks of 9/11, with the general public of today being more security conscious (Wang and Leedham, 2005). This heightened awareness of public security has seen a rise in demand for personal identification systems (Choi, 2009), with newer more complex methods of identification replacing the traditional approaches such as Personal Identification Numbers (PIN) and smart cards (Liu and Silverman, 2001). These traditional identification methods have been criticised for offering limited security; for example PIN numbers can be used by anyone who is privy to such information. Due to their increased reliability and associated heightened security, biometric technology has been introduced to "access control" security in daily life to overcome such shortcomings (Lyon, 2009; Bhattacharyya *et al.*, 2010; Jain *et al.*, 2011). In addition, biometric features are considered more reliable and secure than traditional security measures such as access cards, as these physical traits are difficult to copy and are rarely lost (Wang and Leedham, 2005). Biometric recognition systems are considered one of the most effective security measures for access control. With use of biometric security systems in daily scenarios, and no longer confined to high-security facilities, these systems are required to be user friendly and reliable (Liu and Silverman, 2001; Lyon, 2009).

7.4. Biometric Standards

The rapid development of biometric technologies and their adoption into daily life has created an environment of increased scrutiny of the accuracy and reliability of biometric applications (Deravi, 2008; Grother, 2008). The standardization of biometric technologies was introduced to improve the reliability and interoperability of biometric systems (Grother, 2008). The heightened importance of interoperability is linked to concerns of international security, with the international use of biometric technologies for security purposes; an example of which being biometric passport use in border control (Lin *et al*. 2004).

The International Organization for Standardization working in conjunction with the International Electrotechnical Commission (IEC) established a joint technical committee with the remit of creating a common framework for the implementation and evaluation of information technologies. Subcommittee 37 was established in 2002 to focus solely on the standardization of biometric technologies (Grother, 2008).

Working group 3 of Subcommittee 37 was tasked with standardizing data interchange formats (images and/or extracted features) corresponding to each specific biometric modality. In 2007, the International Organization for Standardization / IEC published its report on vascular biometric image data – ISO/IEC 19794-9.

ISO/IEC 19794-9 defines the standardized biometric database format required to record vascular biometric images (International Organization for Standardization, 2011). Specifications for the recording, storage and transmission of vascular biometric information are listed in conjunction with definitions of content, format and units of measurement required for the exchange and comparison of vascular data images associated with the fingers and hands. In addition, recording standards include space for the illumination under which images were captured, either visible light, infra-red (near or midrange) and mixed.

7.5. Biometric Systems based upon Vein Pattern Analysis

The venous network of blood beneath the skin creates a vein pattern which can be utilised for biometric analysis (Bhattacharyya *et al.*, 2010). The pattern of blood vessels in the human body has already been utilised in a number of biometric systems, most commonly the vessels of the retina and hand (Vacca, 2007).

Retina scans are commonly found in high security environments and are favoured due to their low error rates whilst also being hard to forge. Retina scanners utilise infra-red light to “map” the pattern of blood vessels of the retina, with the capillaries of this area absorbing more IR light than surrounding tissue, resulting in variations of refection intensity (360Biometrics, 2013). The intensity of reflection points is graded and translated into computer code which is subsequently compared to codes already held on the associated database (Jain, 2000). This technology is rarely employed on a large scale as the user must come into close contact with the hardware and then follow a series of prompts to move the eye in a certain direction for the required data to be collected. This process can be time consuming and the close proximity of the machine to the face and eye(s) raise concerns amongst users regarding hygiene and safety (Vacca, 2007).

Biometric scanners detecting vascular patterns in the hand and fingers have become commonplace in today's society, with their use having expanded from high security environments to daily tasks such as "clocking in" machines and border controls. Hand scanners are considered user friendly with many now becoming contactless. These contactless systems eliminate the need to place the hand on a scanner, thus eliminating concerns of hygiene amongst the user population and contamination by trace evidence.

The vascular pattern of the hand is considered an ideal biometric feature as it fulfils all the criteria outlined by Jain *et al* . (2011); that is, the venous system is present in all individuals (Universal), the pattern is allegedly unique between individuals (in that it is sufficiently different between individuals, with research to date having found no two individuals with the same vein pattern), develops prior to birth and remains stable over the course of lifetime (size may change but the arborescent pattern does not, therefore only the pattern is used as the biometric feature for identification) (Bhattacharyya *et al.*, 2010). A major merit of vein patterns for biometric identification is that they are largely invisible to the naked eye, thus providing protection from copying/spoofing, and making them more secure than readily visible biometric features such as fingerprints and facial geometry which are captured externally (Bhattacharyya *et al.*, 2010; Wang and Leedham, 2005; Kumar *et al.*, 2009). In addition to the increased security offered by the internal location of the venous pattern, the pattern is not affected by the external condition of the skin (i.e. dirty hands), and so can be utilised in adverse environments such as construction sites, factories and armed forces (Choi, 2009; Bhattacharyya *et al.*, 2010). As IR imaging of the venous pattern is reliant upon the presence of deoxyhaemoglobin in the blood, vein pattern technology has inherent liveness detection to protect against spoofing (Sharma *et al.*, 2014).

The location of veins beneath the skin makes them largely invisible to the naked eye and other systems of visual inspection unless in close proximity (Bhattacharyya *et al.*, 2010; Wang and Leedham, 2005; Choi, 2009; Kumar *et al.*, 2009). Visible light occupies a wavelength of 400-700nm, which is not adequate to penetrate the skin to visualise the vascular network clearly in all individuals. Near-infrared light however occupies a wavelength band of 800-1000nm and can penetrate the skin up to a depth of approximately 3mm (Choi, 2009). Vein biometric systems utilise near infrared light to exploit the photochemical properties on the venous network to visualise the vein pattern. When exposed to light with a wavelength within the near infrared range (760nm), the deoxygenated haemoglobin of the veins absorb this light. When the resultant image is captured, the deoxidized haemoglobin containing blood vessels appear as dark lines. For biometric systems based upon authentication of vein patterns, the subject's vein pattern in the region of interest is captured using NIR light, extracted from the image as a whole and registered as a template in a database. For access control systems, the vein pattern presented to gain access is verified against the stored database of templates (Bhattacharyya *et al.*, 2010).

The majority of research conducted into vein pattern analysis for biometric use has so far utilised high cost imaging devices as they produce high quality images which are easily processed (Bhattacharyya *et al.*, 2010). More recent work has focused on utilising low cost alternative imaging devices including standard webcams which have been modified to be sensitive to infrared wavelengths to enable imaging of vein patterns. Webcams are sensitive to light of wavelengths in both the visible and infrared spectrum, however built in IR filters are in place to block IR light, allowing only visible light to pass through to the camera. The removal of this internal IR filter and replacement with a visible light filter results in the webcam becoming sensitive to IR light only (Bhattacharyya *et al.*, 2010).

8. The Biological Basis of Vein Pattern Analysis

To comprehend the basis of biometric technology, it is essential to have an understanding of the underlying embryological processes and anatomical features. As this research is concerned with Vein Pattern Analysis of the dorsum of the hand, the formation of the vascular network will be presented, with the aim of elucidating the biological basis for vein pattern analysis in the dorsum of the hand.

8.1. Development of the Vasculature

The primitive embryo does not contain any blood vessels, with the vascular system commencing formation during the third week of gestation (Carlson, 2009). Formation is initiated as the growing embryo is no longer able to receive adequate nutrients from placental diffusion (Sadler, 2012a). The formation of blood vessels commences around day 17, with cells originating in the wall of the yolk sac. These cells form in the splanchnopleuric mesoderm, and coalesce to form "blood islands" (Larsen, 1993).

Haemangioblasts are the precursor cells of blood islands and have the potential to differentiate into either endothelial or haematopoietic cells (Carlson, 2009). Cells forming hemagiogenic cells originate in the primitive streak of the embryo prior to circulation being established. Blood islands contain hematopoietic stem cells, called hemocytoblasts which are responsible for the generation of all cell types found in the blood.

Formation of the vascular network in the embryo is implemented by two distinct mechanisms, vasculogenesis and angiogenesis (Patan, 2000; Vailhe *et al.*, 2001).

The major vessels of the circulatory system (dorsal aorta and cardinal veins) are formed by vasculogenesis, with angiogenesis being responsible for the formation of the remainder of the vascular system (Sadler, 2012a).

8.1.1. Vasculogenesis

Vasculogenesis is the process by which the heart and the primitive vascular plexus of the embryo are formed (Patan, 2000). Vasculogenesis occurs *in situ*, with the differentiation and growth of haemangiogenic cells (Demir *et al.*, 2007). These haemangiogenic cells further differentiate to form angioblasts (endothelial cell precursors) and hemangioblasts (haemopoietic cell precursors) (Cogle and Scott, 2004). Angioblasts coalesce and orientate to form a primary capillary plexus, which undergoes rapid reorganization to accommodate the demands of the rapidly growing embryo. The action of angioblasts is dictated by factors such as the extracellular matrix and growth factors, with both systolic and diastolic pressure impacting upon coalescence (Cox and Poole, 2000). The primary stages of vasculogenesis are represented in Figure 6.

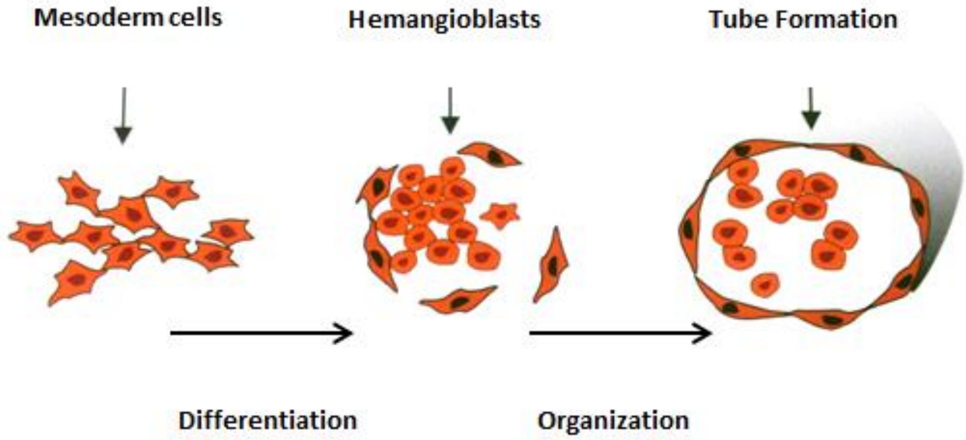


Figure 6. Primary steps in vasculogenesis (Sadler, 2012b)

8.1.2. Angiogenesis

The process of angiogenesis describes how new blood vessels are formed from existing blood vessels via expansion and remodelling of the vascular network (Patan, 2000). During angiogenesis, vessels form via budding of endothelial cells into adjacent areas which are nonvascularised, subsequently fusing with other vessels (Moore *et al.*, 2013). The process of angiogenesis is not limited to the establishment of the vasculature, but occurs throughout life to adapt vascular flow to developing tissues and organs (Carlson, 2009). Angiogenesis occurs as a result of two distinct mechanisms; intussusceptive microvascular growth (IMG), and endothelial sprouting. The mechanism of endothelial sprouting is founded upon the migration of endothelial cells, their proliferation and subsequent tube formation. Intussusceptive microvascular growth (IMG) describes the division of existing vessels by the formation of tissue folds and their insertion into the lumen of already formed vessels.

These secondary vessels are termed inter-vascular tissue structures (ITS). IMG also forms new vessels as loops within the walls of large veins.

8.1.3. Regulation of Vessel Formation

The processes of angiogenesis and IMG are regulated molecularly. Vascular Endothelial Growth Factor (VEGF) and its associated receptors play a crucial role in this regulation (Demir *et al.*, 2007).

8.1.4. The Venous System

By the 5th week of development, three pairs of major veins can be distinguished in the embryo (Figure 7). These are the vitelline veins, the umbilical veins and the cardinal veins. The vitelline veins, also referred to as the opthalmomesenteric veins, are responsible for carrying blood from the yolk sac to the sinus venosus. The umbilical veins carry oxygenated blood to the embryo from the chorionic villi of the placenta, with the cardinal veins draining the body of the embryo (Sadler, 2012a).

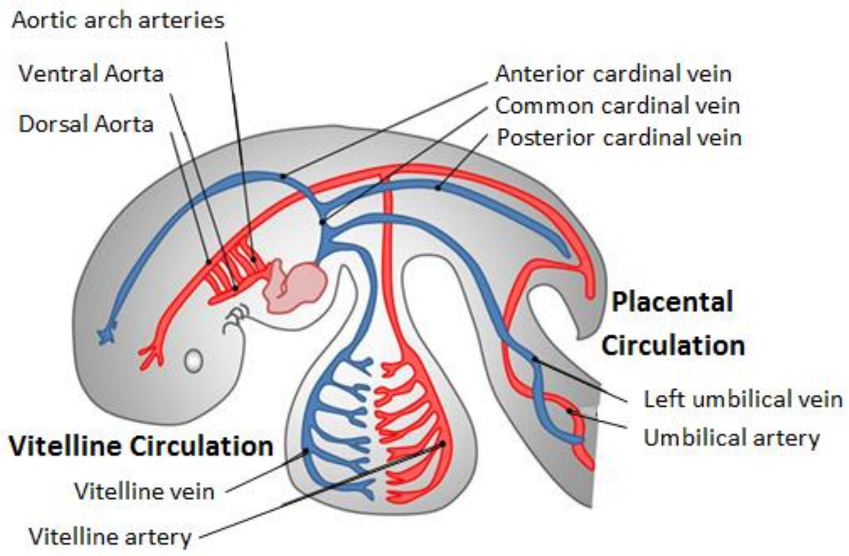


Figure 7. Embryonic circulation (UNSW Embryology, 2013)

The forming veins anastomose at various locations, and when combined with the influences of the local cellular environment and growth factors during vein formation, result in vein patterns which are unique to the individual (in that no other individual has an identical patterning of veins). This uniqueness lead to the biometric application of vein pattern analysis.

8.2. The Mature Venous System

The venous system is not simply a network for the flow of deoxygenated blood back to the heart. Elements of the venous system are also involved with nutrient and fluid exchange, transmission of white blood cells during inflammatory responses and reservoirs of blood (Kerr, 2000).

The structure of veins varies considerably depending upon the venous pressure exerted upon them. Veins are classified as either small-to-medium or large. Small-to-medium sized veins have an adventitia which is well developed, with a thin tunica media, and a tunica intima which lacks a continuous elastic lamina. Large veins such as the pulmonary veins and venae cava have diameters exceeding 10mm. The tunica adventitia found in large veins contains collagen and is much thicker than that seen in small-to-medium veins. The tunica intima is also much thicker than that of smaller vessels, however the tunica media is poorly developed (Kerr, 2000).

8.2.1. The Venous Network of the Hand and Upper Limb

The venous drainage of the upper limb is arranged into superficial and deep vessels (Botte, 2003). The superficial veins ascend in the subcutaneous tissue. The deep veins of the arm accompany the arteries and are interconnected with the superficial system of veins via small perforating veins (Botte, 2003).

8.2.2. Superficial Veins of the Hand and Upper Limb

The primary superficial veins of the arm consist of the cephalic and basilic veins. These veins originate from the dorsal venous network found in the subcutaneous tissue of the dorsum of the hand (Drake *et al.*, 2010).

8.2.3. Dorsal Venous Network

The dorsal venous network of the hand is formed by the venules associated with the digits distally and the dorsal digital venous arches, coalescing to form the dorsal digital veins. The dorsal digital veins ascend on either side of each digit, communicating via oblique branches and coalescing with each other and connections from intercapitular veins. This coalescence results in the formation of three dorsal metacarparl veins, terminating in the venous network of the dorsum of the hand (Botte, 2003).

The distal section of the cephalic vein is formed via the coalescence of the radial section of the dorsal venous network with the dorsal digital veins from the lateral two digits, the thumb and index finger (Figure 8). The medial aspect of the dorsal venous network receives the digital veins of the 4^{th} and 5^{th} digits to contribute to the formation of the basilic vein (Botte, 2003).

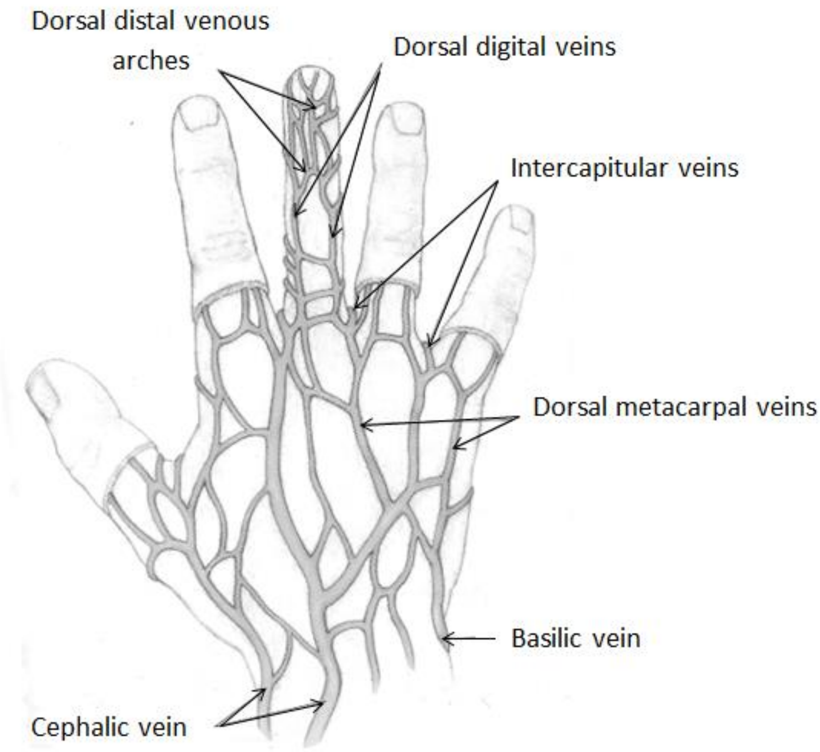


Figure 8. Veins of the dorsal hand and digits (Botte, 2003)

8.2.4. Superficial Venous Palmar Arch

The palmar aspect of the hand contains the superficial venous palmar arch. This network is described as “more delicate” than that of the dorsum of the hand (Botte, 2003). The palmar digital veins form the basis of this arch, draining into the venous network overlying the palmar digits. The palmar digital veins are interconnected with their dorsal counterparts and dorsal metacarpal veins via the intercapitular veins. The intercapitular veins are located within the spaces of the digital web. The palmar veins and these interconnections ascend over the palmar surface to contribute to the median antebrachial, cephalic and basilic veins. The superficial veins of the palm are depicted in Figure 9.

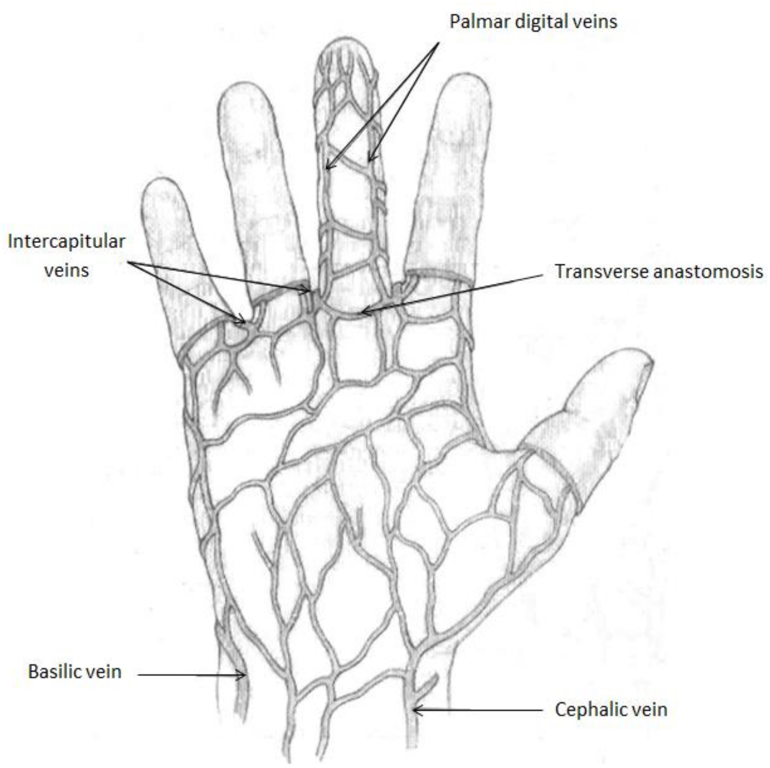


Figure 9. Veins of the palmar hand and digits (Botte, 2003)

8.2.5. Cephalic Vein

The cephalic vein originates from the lateral side of the dorsal venous network, ascending lateral to the wrist to the anterolateral surface of the forearm and later the arm (Drake *et al.*, 2010). The cephalic vein communicates with the medial cubital vein at the anterior aspect of the elbow, passing obliquely to join the basilic vein. The cephalic vein passes between deltoid and pectoralis major to enter the clavipectoral triangle. The cephalic vein passes through the clavipectoral triangle and pierces the clavipectoral fascia to join the terminal portion of the axillary vein (Moore *et al.*, 2011; Botte, 2003).

8.2.6. Basilic Vein

The basilic vein also originates from the dorsal venous network, this time on the medial aspect. The basilic vein ascends medially up the forearm and into the inferior portion of the arm. During ascent through the subcutaneous tissue, the basilic vein pierces the brachial fascia and ascends in parallel to the brachial artery. The basilic vein joins the venae comitantes which accompany the brachial artery, forming the axillary vein (Drake *et al.*, 2010; Moore *et al.*, 2011).

8.2.7. Median Antebrachial Vein

The median antebrachial vein ascends in the middle of the forearm on its anterior aspect. This vein originates from the palmar plexus of the hand, ascending toward the medial side of the anterior forearm, either draining into the basilic vein or forming part of the median cubital vein (Botte, 2003).

The cephalic, basilic and median antebrachial veins are depicted in Figure 10.

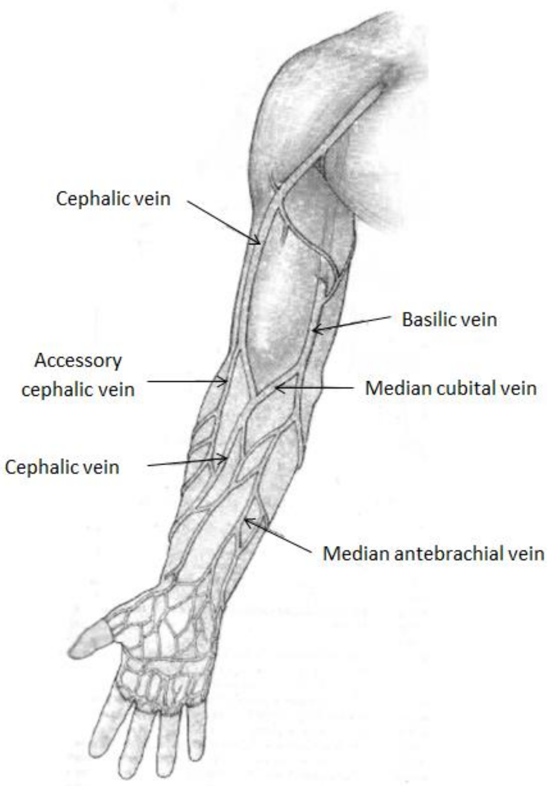


Figure 10. Superficial veins of the upper limb (Botte, 2003)

8.2.8. Deep Veins of the Hand and Upper Limb

The deep veins of the upper limb run internally to the deep fascia. These deep veins are usually paired, anastomosing continually accompanying the major arteries of the upper limb as venae comitantes (Moore *et al.*, 2011). The deep veins of the hand consist of a pair of venae comitantes accompanying the superficial and deep palmar arches. These venae comitantes form the deep palmar venous arch, receiving veins corresponding to the arterial arch branches (Botte, 2003).

9. Visualising the Venous Network

As the venous network is subcutaneous it cannot always be readily visualised, especially in young children and individuals who are overweight, have dark skin, excessive body hair or tattoos (Christie Medical, 2013; Cuper *et al.*, 2013). Clinical imaging of the veins is required for many reasons, such as venepuncture or to gain access for vascular surgery (Zharov *et al.*, 2004).

As the vascular network lies underneath the skin, imaging modalities which employ visible light (wavelength 400-700nm) are ineffective in visualising these structures in some individuals as it is unable to penetrate the tissues overlying the veins (Kumar *et al.*, 2009; Cuper *et al.*, 2013). The location of veins relative to the skin surface is a primary factor determining their visibility within the visible light spectrum. Superficial veins residing closer to the skin surface than their "deep" counterparts (Agache and Humbert, 2004), can be effectively imaged using high resolution digital cameras when factors such as skin pigmentation and body fat percentage are favourable (Wilson, 2010).

The presence of subcutaneous fat overlying the veins has been cited as a determinant factor in the visibility of superficial veins, with low amounts of subcutaneous fat aiding in the visualisation of superficial veins in visible light (Zharov *et al.*, 2004; Chiao *et al.*, 2013). It is noted by numerous authors that whilst body fat percentage remains a determinant factor, skin colour may also greatly obscure the vein pattern when attempting to visualise veins in visible light (Zharov *et al.*, 2004; Chiao *et al.*, 2013).

Whilst it is possible to view the venous pattern of superficial veins in visible light (Zharov *et al.*, 2004; Wang and Leedham, 2006), near-infrared imaging has been established as the most effective method of vein vizualisation and as such has been adopted by the biometric indistry for vein pattern analysis (Wang and Leedham, 2006; Wilson, 2010). In addition, a range of differing imaging modalities utilising near-infrared (NIR) light are employed by medical professionals to determine the location of, and gain acess to veins (Miyake *et al.*, 2006; AccuVein, 2013; Christie Medical, 2013; Wang *et al.*, 2013). These technologies are primarily employed to reduce discomfort to the patient in cases where vascular access sites are not readily identifiable (American Institute of Ultrasound Medicine, 2012; Kelly, 2013).

9.1. Optical Properties of Skin

Skin is made of 3 core components; water, haemoglobin and melanin (Agache and Humbert, 2004). Water absorbs light of wavelengths above 1000nm and below 300nm. Haemoglobin and melanin absorb visible light of wavelengths 400-650nm. An "optical window" is therefore present between wavelengths of 650 and 1000nm (Agache and Humbert, 2004).

Previous research regarding the visualisation of vein patterns has determined that near- infrared light (NIR) of wavelength 880-930nm is the most efficient wavelength for visualising vascular structures as the incident radiation can penetrate the tissues overlying the vascular network (Zharov *et al.*, 2004; Wang *et al.*, 2013) . The optical properties of haemoglobin are exploited by NIR technology, as haemoglobin of the blood absorbs more incident NIR light than surrounding tissue which results in good contrast between the veins and surrounding tissue and a clear depiction of the veins

(Wilson, 2010; AccuVein, 2013; Cuper *et al.*, 2013; Wang *et al.*, 2013). The clearest vein pattern images will therefore be produced when incident light of wavelength closest to the maximum absorption of haemoglobin is utilised.

9.2. VeinViewer Technology

With the recent advancement of imaging techniques, both medical and commercial, a new device designed specifically to view the venous network has been created; VeinViewer also exploits the NIR absorbency of haemoglobin to project the location of peripheral veins directly onto the surface of the skin. This imaging device is capable of visualising vessels up to a depth of 10mm below the dermis.

Such clinical imaging devices have been developed to assist in the visualisation of veins in patients considered as problematic due to their age, body fat percentage and skin colour. Infants are considered the most difficult subjects for vein access due to their high percentage of adipose tissue, with mature individuals possessing a high percentage of body fat also being identified as problematic in terms of vein visualisation and access (Mbamalu and Banerjee, 1999; Cuper *et al*., 2013).

In addition, practitioners find traditional means of vein visualization (by the naked eye, or visible light photography) difficult in individuals with dark skin due to the melanin content (Mbamalu and Banerjee, 1999; Chiao *et al.*, 2013). Medical imaging and biometric technologies utilise near infrared imaging, as the incident wavelength penetrates the adipose and melanin containing cells to be absorbed by the deoxyhaemoglobin of the veins (Soni *et al.*, 2010; Mansoor *et al.*, 2013).

9.2.1 Clinical VeinViewer

Clinical VeinViewers are utilised in hospital settings to assist in the visualization of peripheral veins (Christie Medical, 2013). These devices project near-infrared light onto the area of interest, with absorbed and reflected light being identified by the device processor, which then projects a real time digital image of the veins onto the skin surface (Christie Medical, 2013). These devices are available in both stationary and hand held models. An example of a hand held device and the resultant real time image are provided in Figure 11.

Figure 11. Hand held clinical VeinViewer

9.2.2 Commercial VeinViewer

For the purpose of this research, a low cost alternative to the clinical VeinViewer is utilised to image the venous network in the dorsum of the hand. This device utilises the same principles as the clinical model, but presents the venous image on a computer screen rather than on the skin. This commercial VeinViewer is in essence a webcam; a USB powered recording device, with inbuilt NIR illumination source and no IR blocking filter (Figure 12). The image is processed by an associated computer software programme and displayed on the computer screen in real time (Figure 13).

Figure 12. Commercial VeinViewer

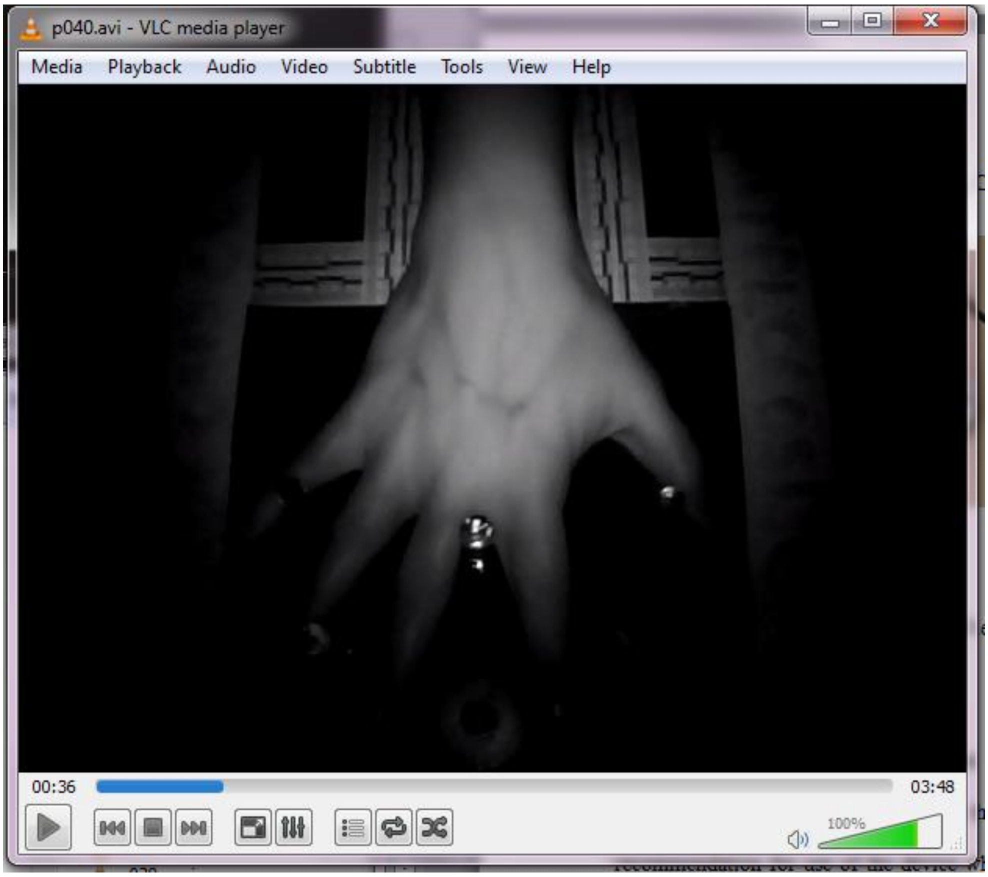


Figure 13. Commercial VeinViewer image displayed on computer screen

It is this device which will be compared to the standard DSLR camera currently employed for obtaining images of suspects' hands in the custody suite, with the aim of this study being the recommendation for use of the device which enables the best visualisation of the vein pattern information. This objective is presented on the premise that the more biological information that can be visualised, the greater data for biometric analysis and hence more statistically robust analysis for the purposes of suspect - offender comparison.

10. Materials and Methods

This chapter will detail the process undertaken to obtain the infrared images for use in the comparison study. The materials and methods employed for data collection are described, with the resultant statistics from these images presented in the results section. The data collection process and results obtained are then discussed, with conclusions being drawn and recommendations for future research being presented.

10.1. Participant Recruitment

An outline of the study and an invitation to participate was sent out to all staff and students via the University of Dundee's weekly e-mail distribution programme, the School of Medicine weekly bulletin, and a collective email to the College of Life Sciences (Appendices A-C, respectively), with participants being recruited via an opt-in procedure. Those who wished to participate were asked to contact the principal investigator to register their interest, while those who did not wish to participate could disregard the email correspondence. Participants who responded to the initial email where provided with further information regarding participant involvement (Appendix D) and enrolled as participants. It was made clear to all, that participation was on a voluntary basis, with participants having the right to withdraw their consent at any time, without explanation. Information sheets provided to all participants gave the contact details of the Principal Investigator and project supervisors should the participants wish to ask any questions.

In accordance with the ethical guidelines as stipulated by The University of Dundee Code of Practice for Research Ethics on Human Participants, participants were not enrolled in the study unless it was demonstrated that they understood the requirements involved in participation. To ensure that the participants were able to give informed consent, detailed information on the data acquisition procedure and data use were provided, with the participant being encouraged to direct any queries to the Principal Investigator.

Upon obtaining informed consent from the participants, they were enrolled in the study and provided with a personal information questionnaire requesting details relevant to the study and a brief health questionnaire (Appendix E). The applicant was reminded that they could refrain from providing information which they did not wish to divulge.

This recruitment process resulted in a research sample of 83 participants; 48 females, 35 males aged 19 to 63 years, with an average participant age of 33 years. Participant statistics will be discussed in greater detail in the results section of this chapter. Participant age was the principal exclusion criterion for this study, as all participants were required to be aged 18 years or older at the time of data acquisition.

10.1.1. Confidentiality and Anonymity of Participant Information

At the time of involvement, each participant was informed that all data would be anonymized and kept confidentially in accordance with the Data Protection Act (1998), with the participant having the right to obtain a copy of any personal information held, and the right to have this information removed from the data set at any time upon request to the Principal Investigator.

Upon enrolment, each participant was assigned a unique reference number (URN) to maintain anonymity. All related information associated with each participant (consent form, questionnaire etc.) was assigned the same URN. Images taken of each participant were catalogued according to their URN and stored on a secure image database, subject to the same security restrictions as participant information. All data was secured in compliance with the Data Protection Act 1998 with all paper forms being stored on university premises in a locked cabinet. The data in these forms, once completed and filed, was copied in electronic format and stored on a password restricted database with access being limited to the Principal Investigator.

10.2. Image Acquisition

The consent of each participant was sought to having still images taken of the dorsum of each hand using a Digital Single Lens Reflex (DSLR) camera, and a real time video recorded simultaneously using the VeinViewer USB camera. Both imaging modalities captured images in IR with the participants being informed of this and the fact that there are no known health and safety risks associated with IR photography. The participant consent form provided the opportunity for the participant to refrain from having either set of images taken/recorded, however any images related to an individual wishing to do so would be omitted from analysis as a direct comparison between the two imaging modalities could not be accomplished.

Images were captured using the set up procedure as described by Jain et al. (1999) and depicted in Figure 14. This set up comprised a digital camera, a light source emitting visible light and a platform on which to place the hand. As the images were captured concurrently, the set up for both imaging devices was combined to ensure that direct comparison could be made between the images. To enable simultaneous capture of images with both devices, the VeinViewer was placed below the DSLR at an angle of 118^0 to capture the region of interest. It is acknowledged that this angular positioning results in a slight variation between the views of the imaging devices, however initial image analysis highlighted no additional variables such as shadowing. Whilst the VeinViewer instruction manual states an optimum focal length of 20cm (RM Education, 2012), initial observations found a high degree of white-out in images. For this reason, additional tests were undertaken prior to data collection to determine the optimum placement height for the VeinViewer. To achieve this, the VeinViewer was positioned at 1cm intervals with the resultant images being assessed for white-out. An optimum placement height of 37cm was determined. Both imaging devices where attached to a photographic stand to ensure stability, with images being captured from above. Figure 15 demonstrates the positioning of the VeinViewer below the DSLR camera.

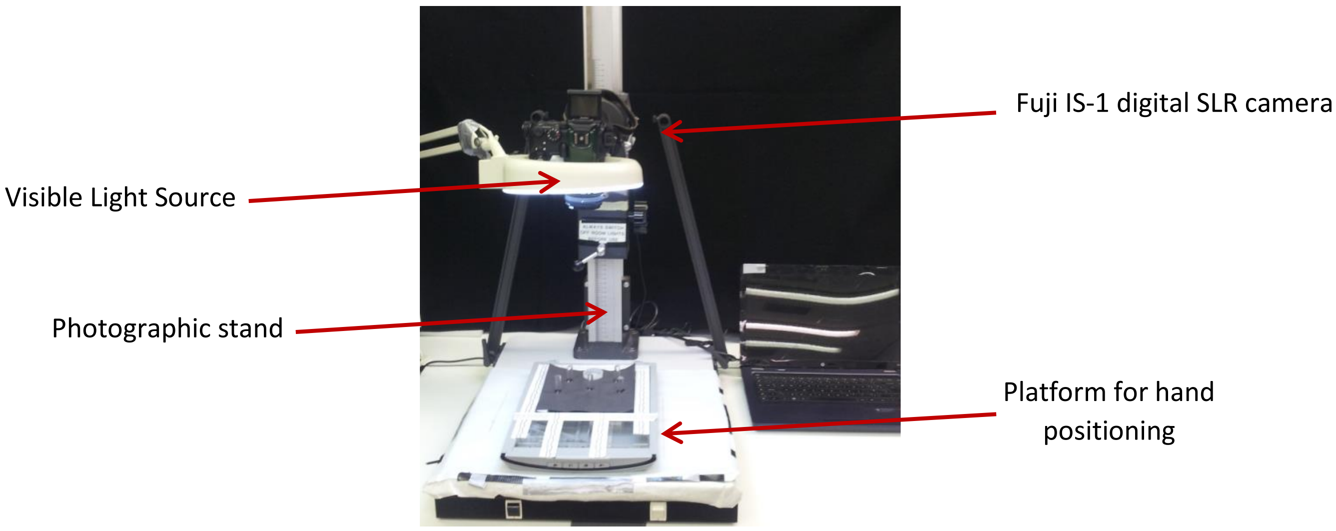


Figure 14. Equipment set up for image capture

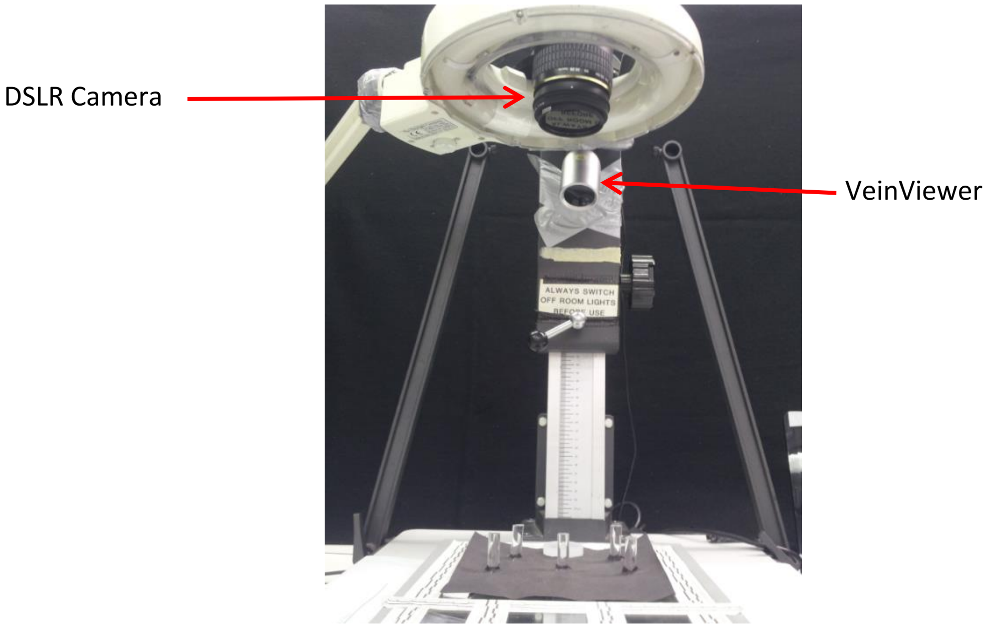


Figure 15. VeinViewer positioned below DSLR

The platform on which the hand was placed (Figure 16) consisted of a flat plane scanner bed fitted with pegs which served to direct the positioning of the hand. The platform area was framed by scale tape to enable images to be scaled. During initial tests it was noted that the Perspex surface of the platform reflected the IR light source, resulting in distortion of resultant images. To prevent this distortion, a sheet of black photographic paper was adapted to be positioned over the pegs whilst ensuring that the scale was still visible. The data set up was not altered throughout the data collection process, with all settings checked regularly, prior to each set of data collection. The set up procedure for image capture is provided in Appendix F.

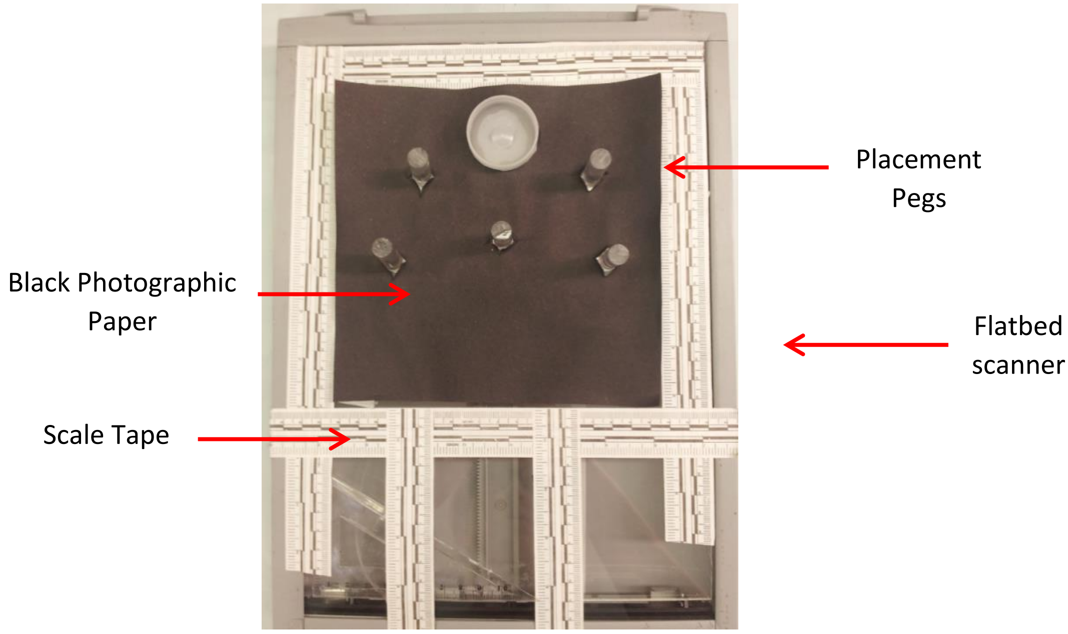


Figure 16. Platform for hand placement

Participants were asked to remove any jewellery which may obstruct the region of interest (ROI) to be imaged, and were shown the correct placement of the hand with the right hand being imaged first. Photographs were taken of the dorsum of the hand in a series of positions; fingers extended and semiflexed (exemplified in Figures 17 & 18 respectively, DSLR images depicting these hand positions). Once all images had been taken of the right hand, this was then repeated for the left hand.

Figure 17. Fingers Extended Position

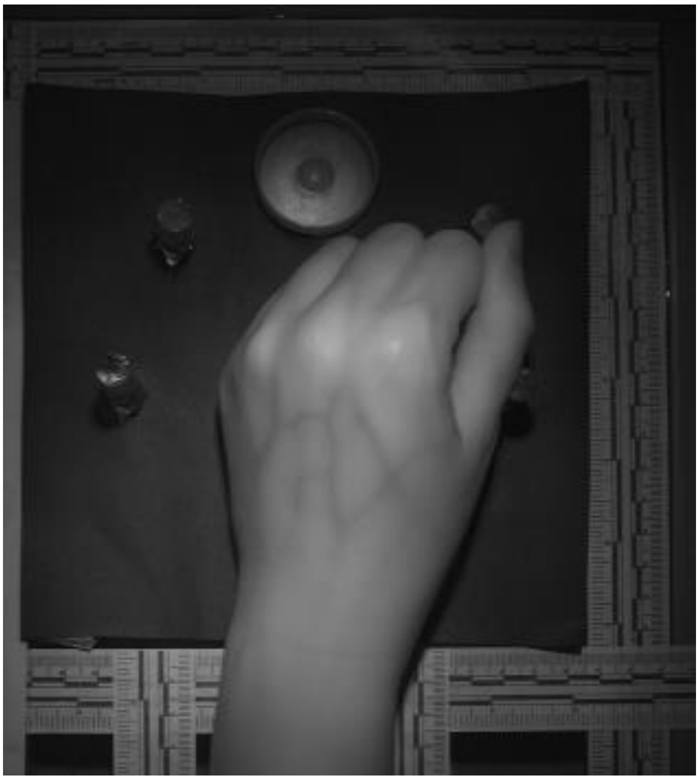


Figure 18. Semiflexed Position

Data collection for each individual occurred on the same day, with each participant being photographed on only one occasion. As a result, there were 83 image capture sessions, one for each participant.

A total of 1992 images were captured for compilation of this database. This total is comprised of 24 images per individual; 16 DSLR images, and 8 images taken from VeinViewer footage. Two sets of DSLR images where captured at different resolutions, to enable comparison of the highest and lowest settings of the DSLR. Tables 3 and 4 outline the image combinations for each imaging modality. Images of each participant's hands were extracted from the VeinViewer video footage at the point when the subject's hand was firmly positioned in the prescribed manner.

Table 3. Summary of Database Images

IMAGING METHOD	**IMAGES PER HAND**	**IMAGES PER INDIVIDUAL**
DSLR	8	16
VeinViewer	4	8
Total	12	24
	Total number of database images:	**1992**

The decision was taken to omit the semiflexed hand pose (Figure 18) as participants found it difficult to maintain a uniform positioning of the hand, which introduced a variable for which there was no control. Resultantly, only the images of each hand in the fingers extended position (Figure 17) were analysed.

In addition to image capture, consent was also sought from each individual to obtain measurements of body fat percentage (BF%) using electronic scales. Approximately 38% of individuals refrained from participating in this aspect of the study.

10.2.1 Still Image Capture

For each participant 16 still images were captured; 8 images of the right hand, and 8 images of the left hand. Each hand had images taken in the prescribed positions , one set with the day lamp light source on, and another with the day lamp off. These image sets were taken using two resolution settings of the camera; 9MP and 0.3MP. These megapixel settings were chosen to enable direct comparison with the VeinViewer which has a resolution of 0.3MP, and to facilitate analysis between the maximum settings of the DSLR camera (9MP) and the VeinViewer.

Table 4 lists the image combinations captured for the right hand of each individual using the DSLR. The data in this table is presented in the order in which the images were taken.

Table 4. DSLR Image Combinations for Right Hand

Image Number	Side	Hand Position	DayLamp ON/OFF	Image Resolution (MP)
1	Right	Extended	ON	9
3	Right	Alternative	ON	9
4	Right	Extended	OFF	9
6	Right	Alternative	OFF	9
7	Right	Extended	ON	0.3
9	Right	Alternative	ON	0.3
10	Right	Extended	OFF	0.3
12	Right	Alternative	OFF	0.3
Total Number of DSLR Images for Right Hand				**8**

Camera Specifications

Still images were captured using a Fuji IS-1 Digital Single Lens Reflex (DSLR) camera. The Fuji IS-1 camera used in this research does not have an inbuilt infrared blocking filter in front of the camera sensor. This adaptation results in a high sensitivity range which is capable of capturing images under infrared light. This property of the camera results in its use in forensic photography for both medical and police purposes, for example when examining documents in forgery investigations or enhancement of tattoos (Duncan, 2010). The light sensitivity and image resolution (measured in megapixels) for this camera can be adjusted, thus allowing settings to be altered to enable direct comparison with images taken using the VeinViewer camera.

ISO is a measure of the light sensitivity of the image sensor of a camera; a higher ISO indicates greater light sensitivity and so is generally utilised in dark settings. A lower ISO indicates a lower sensitivity to light, resulting in images of a finer grain. Shutter speed is directly related to ISO, with a lower ISO having a slower shutter speed (Rowse, 2012). For this study, an ISO of 80 was selected as this was the lowest ISO setting available and so would produce the finest grain / most detailed images. Changing the ISO automatically adapts the shutter speed and exposure. Exposure refers to the amount of light that enters the Charged Coupling Device (CCD) of the camera, which acts to convert captured light in to digital data that is recorded by the camera. As such, exposure determines the brightness of the image. A combination of aperture and shutter speed determines the exposure of the images. For this research, the Auto Exposure (AE) setting on the camera was selected to achieve optimum images, accounting for the brightness of the subject of the image, or the sensitivity setting of the camera.

To enable images to be captured in infrared, a 780nm lens filter was attached to the camera lens via a standard step down ring to isolate specific light wavelengths and block visible light. This lens filter was chosen due to its closeness to the IR wavelength utilised by the VeinViewer (760nm). A filter of matching wavelength to that of the VeinViewer’s 760nm was not available to the Principal Investigator at the time of data collection. As the VeinViewer records images in greyscale, the DSLR camera was set to black and white mode for image capture.

The auto focus setting was selected for the camera, with part depression of the shutter focussing the image. Full depression of the shutter acted to capture the desired image.

As the purpose of this study was to compare directly IR images taken using the DSLR and the recordings from the VeinViewer camera, the VeinViewer’s IR light source was left on whilst still images were being captured. This resulted in both sets of images being subjected to the same lighting conditions.

10.2.2. Video Capture

The VeinViewer camera was installed directly below the DSLR as shown in Figure 15, at a height of 37cm and an angle of 118^0 to accommodate the hand placement area of the platform.

For each individual a single video was captured using the VeinViewer camera. This video was captured simultaneously to the acquisition of still images; as such, the video depicts all 16 hand poses undertaken by each individual. In contrast to the DSLR camera, neither the light sensitivity nor resolution of the VeinViewer camera can be altered. From these video files, screen shots were captured of the hand in the prescribed positions under the two light settings (ON/OFF), resulting in 8 images per individual. Table 5 lists the screen shot images captured from the VeinViewer video data for the right hand of each individual. The data in this table is presented in the order in which the images were taken.

Table 5. VeinViewer Image Combinations for Right Hand

Image	**Side**	**Hand Position**	**DayLamp ON/OFF**
1	Right	Extended	ON
3	Right	Alternative	ON
4	Right	Extended	OFF
6	Right	Alternative	OFF
Total Number of Images for Right Hand			**4**

VeinViewer Specifications

The VeinViewer is a USB powered device that utilises near infra-red light to capture images of the veins in AVI video format. This camera was connected to a laptop with images being stored on a secured external hard drive. The video capture location for each video was saved as a file bearing the URN of the participant.

As the VeinViewer captures real-time video images rather than still images, the resolution is provided in Video Graphics Array (VGA) rather than Megapixel format (MP). VGA is utilised for personal computer based image systems, producing square pixels that were traditionally favoured as they match those of a computer screen (TechTerms.com, 2012). The standard VGA format is 640*480, that of the VeinViewer. To convert VGA to MP, the resolution capacity (640*480) is multiplied; 640 X 480 = 307200, and then divided by 1048576. This gives a megapixel value of 0.3072 which when rounded to the nearest whole is 0.3MP (Anon., 2011). The maximum frames per second setting (fps) of the VeinViewer was selected to minimise the effects of interlacing.

10.3. Body Fat Percentage Measurement

During imaging sessions participant consent was sought to obtain measurements of body fat percentage. A total of 52 participants had this measurement recorded.

Body fat percentage measurements for each arm of each participant were calculated using Tanita BC-601 Innerscan electronic scales. To obtain readings using this equipment, the age, height, sex and activity level of the participant was required.

The height of each participant was measured using a clinical height measurement scale. Measurements were recorded in centimetres and rounded to the nearest whole centimetre as this was the format required for input in the Tanita scales. The activity level of each subject was determined on a scale of 1 to 3, with 1 being mainly sedentary and 3 being the partaking of regular exercise. The guest setting was selected for each participant prior to stepping on the scales. It was ensured that the feet of the participant were firmly in place on the contacts of the scales, and the hand console was held correctly with the arms being held diagonally away from the body as stipulated in the user manual (TANITA, 2013) and shown in Figure 19. Once the scale had indicated that measurement was complete, the participant was asked to step off the scales. Age, height, sex and activity level information was then entered to calculate the body fat percentage.

For accurate measurements, participants were asked to remove their shoes and socks prior to height and body fat percentage data collection. In the interests of hygiene, both the electronic and height scales were disinfected with antibacterial wipes between each participant.

Accuracy of the scales was tested at the start of each data collection session, with the body fat percentage measurements of the Principal Investigator being collected upon initial set up, and again 10 minutes later, prior to the commencement of data collection.

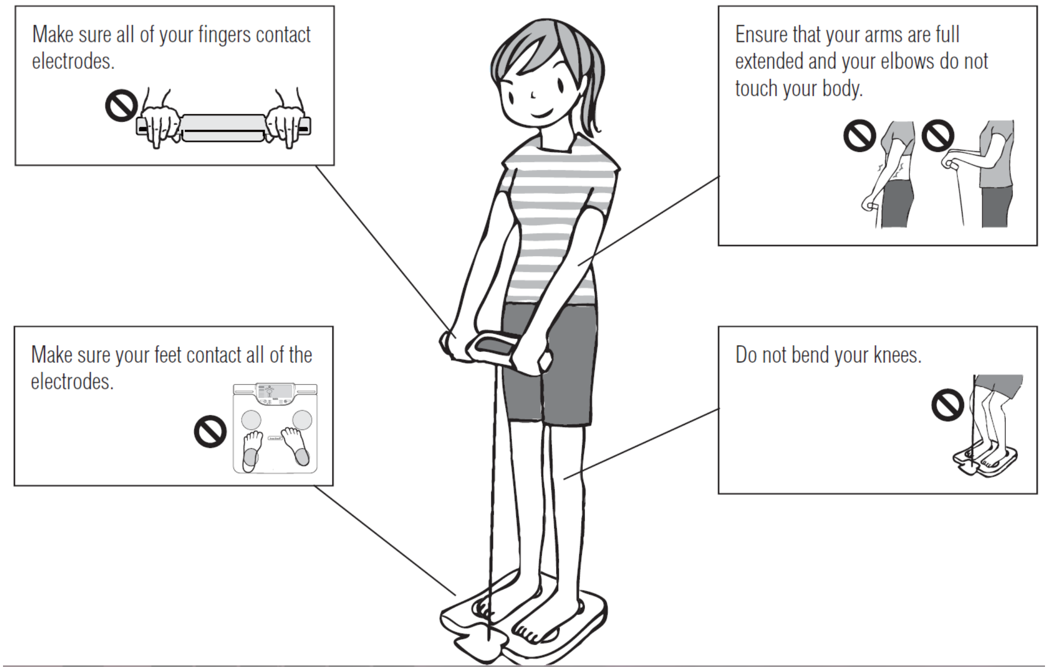


Figure 19. User Instructions for Tanita electronic scales (TANITA, 2013)

The primary exclusion criteria for individuals having their body fat percentage measured using the Tanita Innerscan electronic scales was the presence of a pacemaker or pregnancy. This exclusion criteria follows the recommendations published in the user manual (TANITA, 2013) as there is a small risk to the aforementioned groups. All 52 participants consenting to have their body fat percentage measured were able and willing to use the electronic scales provided.

10.4. Database Summary

Following the participant recruitment process, a total of 98 participants were enrolled. From these participants, a total of 83 were utilised in the study (Table 6). The remaining 15 individuals were excluded as the region of interest was not fully visible in the VeinViewer images due to a technical fault out with the control of the Principal Investigator.

Table 6. Total number of participants including those later excluded

SEX	**NUMBER OF INDIVIDUALS**	**EXCLUSIONS**
Male	41	6
Female	57	9
Total	98	15
	FINAL SAMPLE SIZE	**83**

The final sample of 83 individuals consisted of 35 males and 48 females of age range 19 to 63 years old as outlined in Table 7.

Table 7. Sample Distribution According to Sex and Age Range

SEX	**NUMBER OF INDIVIDUALS**	**Age Range**	**Average Age**
Male	35	19-63	33
Female	48	21-63	33
Total	**83**		

As it has been noted by various authors that the level of melanin in the skin has an impact on the ability to visualise veins (Chiao *et al.*, 2013; Mbamalu and Banerjee, 1999), participants were asked to provide details of their ethnicity on the participant questionnaire. The primary groups provided for classification were White, Black, Asian and Mixed. Under each of these sets, sub groups were provided into which the participant could self-classify, with space to provide an alternative classification if desired. Table 8 outlines the number of individuals identifying with the main ethnic groups utilised for classification in this study.

Table 8. Sample Distribution According to Primary Ethnicity Groupings

ETHNICITY	NUMBER OF INDIVIDUALS
White	80
Black	0
Asian	3
Mixed	0
Total	**83**

Table 9 shows the sub divisions of ethnic groups into which individuals self-classified using the participant questionnaire provided during the data collection process of this study.

Table 9. Sample Distribution According to Ethnicity Sub-Groupings

ETHNICITY	NUMBER OF INDIVIDUALS
White British	66
White Welsh	1
White Irish	1
White European	7
White American	4
White Arab	1
Asian; Malaysian	2
Asian; Chinese	1
Total	**83**

10.5. Image Tracing

Upon collection of all images for each participant enrolled in the database, each image was traced to determine the visibility of the vein pattern using each imaging modality. Image tracing was conducted following the method developed by Meadows (2011). All tracing was undertaken using Adobe Photoshop CS5.1. Tracing was conducted on one image type at a time. For example, the first set of tracing was conducted on all DSLR images of the right hand in the fingers extended position (Figure 17). To minimise the effect of image memory, the next set of traces undertaken were of the left hands of all participants, with each tracing session of the same hand being conducted at intervals of no less than 48 hours.

Each image to be traced was opened in Photoshop, with the original image being saved as a Background Level. The Layer tool was then utilised to create a duplicate layer to which changes could be made without altering the original image (Figure 20).

As this study utilises the tracing method created by Meadows (2011), which quotes high percentage inter-observer reliability and repeatability rates, no additional tests of this nature were undertaken for the purposes of this study due to time constraints.

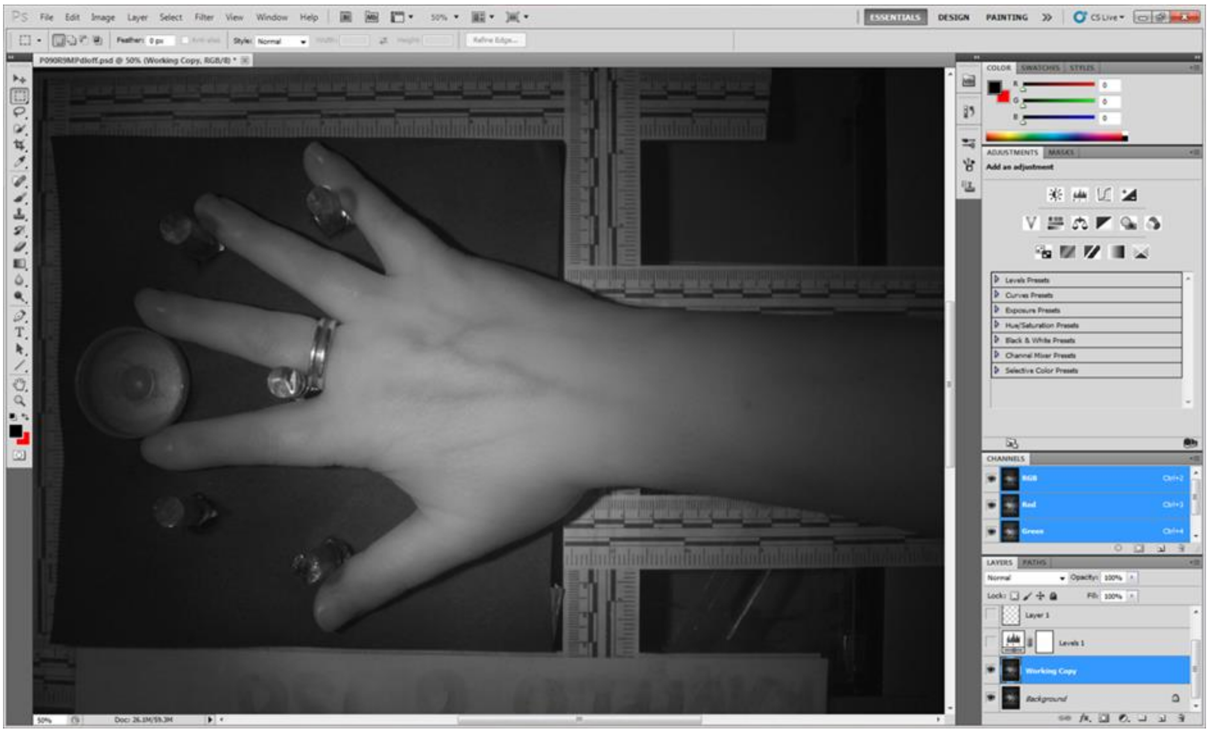


Figure 20. Duplicate image layer created in Photoshop

Images were then enhanced using the Auto Contrast tool to adjust the contrast of the duplicate image automatically, making shadows appear darker and light areas appear brighter (Figure 21). A new layer was then created using the Duplicate Layer tool, being labelled Trace 1. It is on this layer that the vein pattern was traced using the Photoshop Brush Tool (Figure 22).

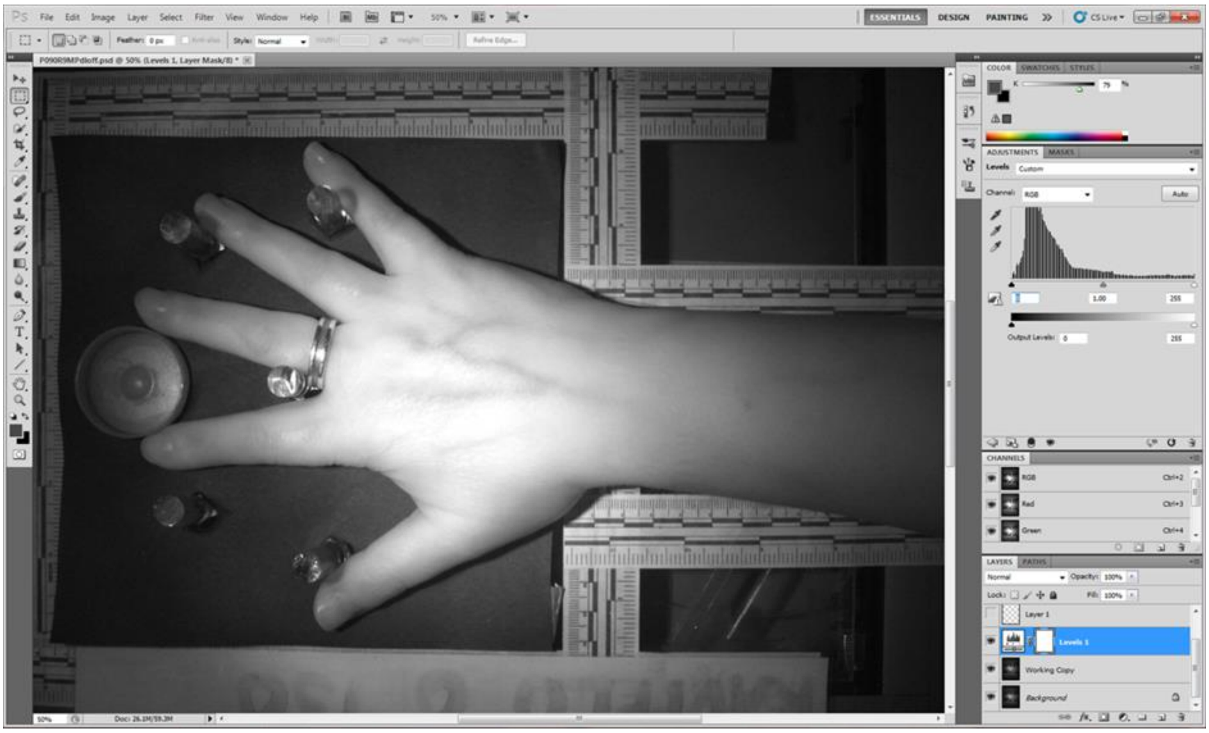


Figure 21. Auto Contrast Tool utilised to automatically adjust image contrast

Tracing was conducted using an Intuos 8.8" X 5.5" graphics tablet and stylus pen. Master Diameter of the Brush Tool was adjusted depending upon the resolution of the image being traced. Images of 9MP resolution were traced using a brush of diameter 3pixels, with 0.3MP images being traced using a brush 1 pixel in diameter. This difference was necessary as the 3 pixel brush when used on the 0.3MP images resulted in thick blurry lines which often obscured surrounding features of the vein pattern.

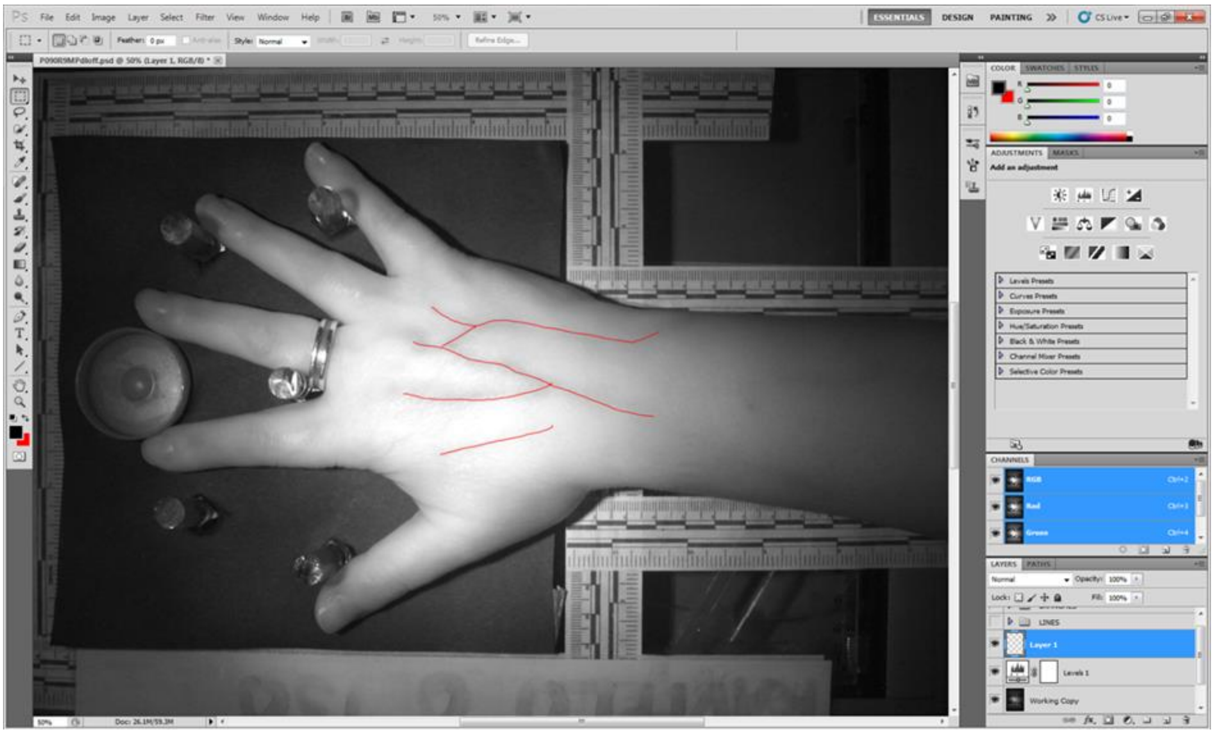


Figure 22. Tracing of the visible vein pattern using the Brush Tool

Upon completion of tracing the visible vein pattern, the Photoshop file comprising all layers for each image was saved under the full file name prefixed by the letter T for purposes of readily identifying that the image had been traced. For example, the file name of a traced image of the right hand of participant 001, taken using the DSLR camera with the day lamp on would be labelled as follows in Figure 23;

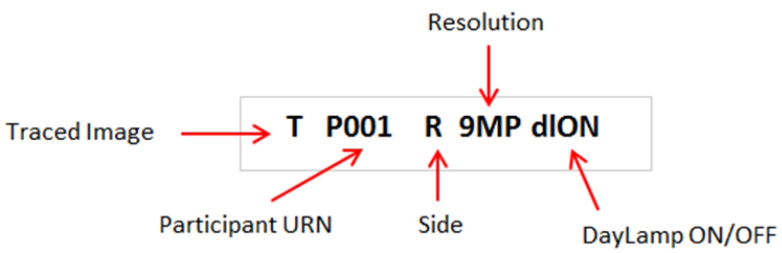


Figure 23. File names associated with DSLR images

VeinViewer images are labelled similarly, with the letters VV preceding the side (Figure 24). For example; T P001 VV R dlON. As the VeinViewer does not have the capacity to alter image resolution, images were all captured in the same resolution (0.03 mega pixels) with the redundant image resolution code being excluded from labelling.

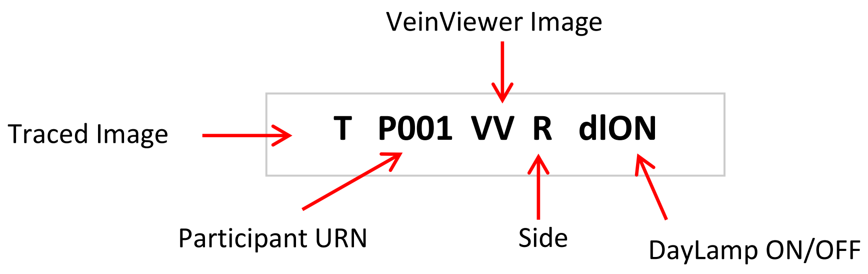


Figure 24. Label associated with VeinViewer image

10.5.1. Labelling Features

Upon completion of tracing the visible vein pattern for each image, all identifiable features of the trace were labelled. Labelling was undertaken in a methodical manner, starting at the distal phalanges and moving proximally, and labelling the top of the image (starting with the fifth digit / little finger) prior to proceeding downwards (towards the first digit / thumb).

Traces were analysed for the presence of the 4 recognised features of vein pattern networking; Line, Branch, Island and Intersection. A brief description of each feature and the labels used to denote them are summarised from the work of Meadows (2011) and presented in table 10.

Table 10. Vein Pattern Features

FEATURE	DESCRIPTION	LABEL	EXAMPLE
Line	Single line with clear beginning and end point	Uppercase Letter	Figure 25
Branch Point	Point where a line splits from original source (without being the main course of another line)	Lowercase Letter	Figure 26
Island	An isolated area enclosed by lines	Greek Letter	Figure 27
Intersection	Points where previously defined lines cross	Numerical Value	Figure 28

Features identified in each image were denoted using their corresponding labels using the Type Tool of Photoshop. Each label was assigned a unique layer on top of Trace 1 layer. Once all features were labelled, labels identifying the same features were grouped to create a single layer identifying each feature. In other words, all labels indicating a line were grouped to form a single layer labelled Lines.

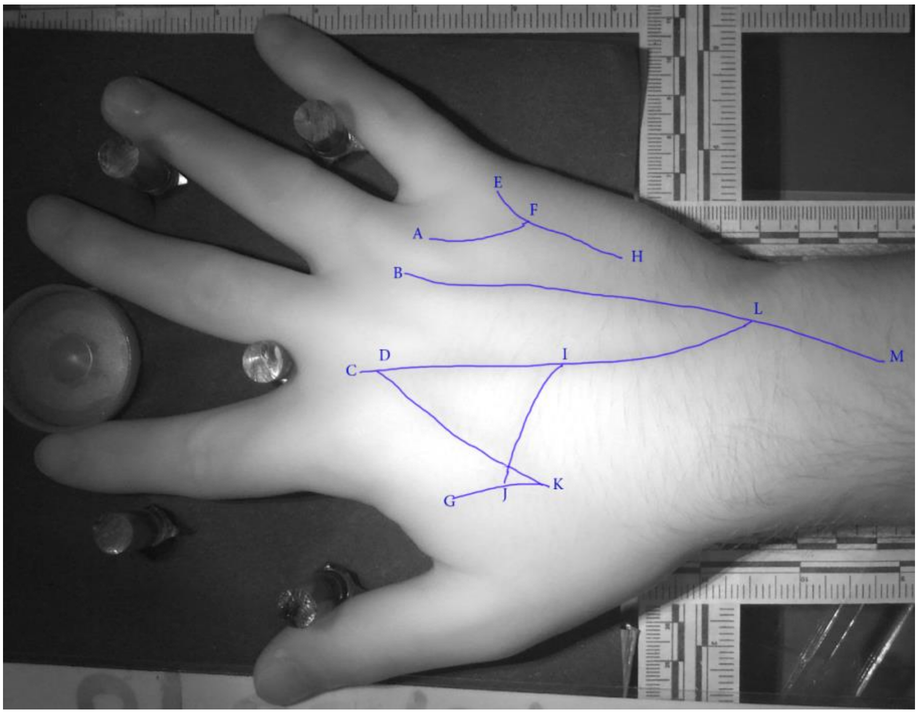


Figure 25. Labels assigned to lines

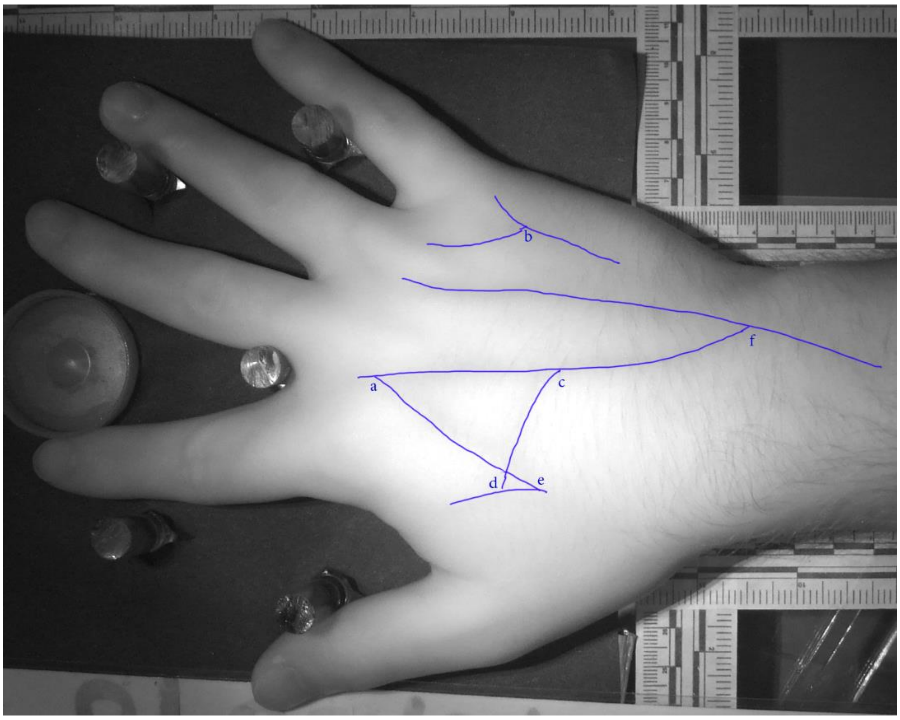


Figure 26. Labels assigned to branches

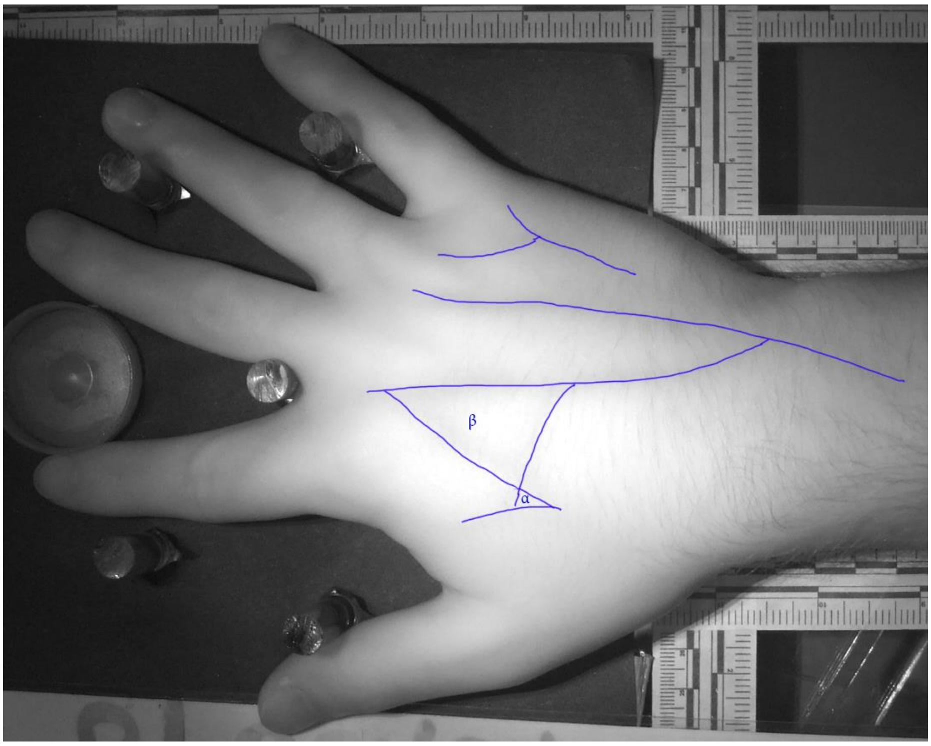


Figure 27. Labels assigned to Islands

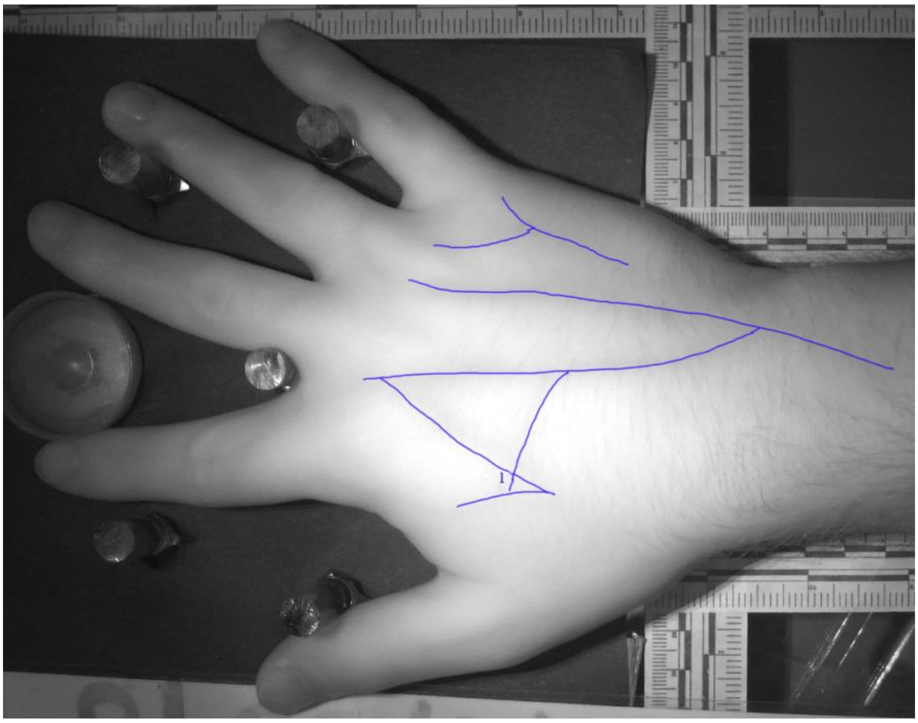


Figure 28. Labels assigned to Intersections

10.6. Comparison of DSLR and VeinViewer Images

To assess which imaging modality enabled the vein pattern features to be more clearly visualised, feature layers for each image were compared. The feature count for each feature type was calculated per individual, with the totals for VeinViewer and DSLR images being compared. This data was recorded in Excel, as illustrated in Figure 29.

Participant	Feature	Feature Total per Image Type					
		9MPdION	9MPdIOFF	0.3MPdION	0.3MPdIOFF	VVdION	VVdIOFF
P002L	Line	24	36	30	19	19	24
	Branch	14	24	24	10	10	14
	Island	3	8	9	2	2	3
	Intersection	0	1	0	0	0	0
		41	69	63	31	31	41
P002R	Line	13	8	9	10	14	9
	Branch	6	3	2	5	5	6
	Island	1	1	1	2	2	2
	Intersection	1	1	2	2	1	1
		21	13	14	19	22	18
P003L	Line	11	20	18	7	12	10
	Branch	5	10	9	2	6	5
	Island	1	1	1	0	0	0
	Intersection	1	1	1	1	0	0
		18	32	29	10	18	15
P003R	Line	16	8	9	11	11	7
	Branch	8	3	4	6	5	3
	Island	1	1	1	1	0	0
	Intersection	1	0	1	0	0	0
		26	12	15	18	16	10
P004L	Line	18	28	13	15	16	14
	Branch	9	14	7	7	9	8
	Island	2	3	1	1	1	1
	Intersection	0	1	0	0	0	0
		29	46	21	23	26	23
P004R	Line	26	17	26	28	10	18
	Branch	17	9	17	18	5	8
	Island	6	2	7	7	1	4
	Intersection	2	0	2	3	0	3
		51	28	52	56	16	33
P005L	Line	6	8	6	7	10	12

Figure 29. Recording sheet utilised to calculate the frequency of each feature type per individual

The total feature counts obtained from the data set traces are provided in Appendix G. Once feature data associated with each imaging modality and resolution had been recorded for all participants, statistical analysis was then conducted.

11. Results

Statistical analysis of the feature count data was conducted using SigmaPlot.

Feature count data recorded for each individual using Microsoft Excel was indexed to allow importation of this data to SigmaPlot, where statistical analysis could be conducted.

A new blank notebook was created in SigmaPlot, with the indexed data from Microsoft Excel being imported using the Import Tool under the worksheet tab.

Under the assumption that the data collected for this study was drawn from a normally distributed population with the same variance, parametric tests were suitable for analysis, with analysis of variance (ANOVA) being the chosen statistical test to assess the research findings.

As the data collected from this study included three experimental factors (individual, feature type and imaging modality/resolution), a three way analysis of variance (ANOVA) was chosen, with Feature Count being utilised as the dependent variable. Feature count was chosen as an indicator of how much vein pattern information could be visualised by each imaging device. As feature count is calculated from the sum of individual Feature Types, further analysis was subsequently conducted to determine the capability of each imaging device to distinguish individual feature types. This analysis presented statistics of percentage data loss.

The report produced from this statistical analysis is presented in Table 11, showing the degrees of freedom (DF), sum of squares (SS) and mean squares (MS) values for each factor tested. The corresponding F statistics and P values are also provided in the far right hand columns.

Table 11. Summary report of Three Way ANOVA analysing the significance of the factors; Camera Type, Feature Type and Individual on Feature Count

Factor	*DF	SS	MF	F	P
Camera Type	5	1312.89	262.58	112.33	<0.001
Feature type	3	92606.75	30868.92	13205.46	<0.001
Individual	165	19516.88	118.28	50.60	<0.001
Residual	*2475*	*5785.53*	*2.34*		
Total	*2648*	*139444.50*	*46.75*		

The above ANOVA summary demonstrates that as P vales for the 3 experimental factors are less than 0.05, there is a significant interactions between;

1. Camera type and feature count

2. Feature type and feature count

3. Individual and feature count

On the basis of the initial three way ANOVA report, additional statistical tests were conducted to assess the relationships between the aforementioned experimental factors and their levels (for example, the levels associated with individual include sex and body fat percentage, whereas the levels associated with imaging device include resolution and daylight) and how these variables interact to influence the amount of feature count data observed in images obtained using each camera type. Table 12 below summarises the outcome of a complex stepwise ANOVA exploring the interactions between each variable.

**DF calculations for;*
- Camera Type: 2 cameras, VeinViewer and DSLR. VeinViewer images obtained with daylight ON and OFF (n=2). DSLR images obtained with daylight ON and OFF, and at two resolutions, 0.3MP and 9MP (n=4). DF = n-1. (4+2)-1=5
- Feature Type: 4 types of vein pattern feature, Lines, Branches, Islands, Intersections (n=4). DF=n-1. (4-1)=3
- Individual: 83 participants, Right and Left hands utilised (n=83x2). DF=n-1. (166-1)=165

Table 12. ANOVA summary of interactions between variables

Factor	DF	SS	MF	F	P
Camera	1	2425	2425.40	23.95	1.28e-06
Sex	1	2671	1335.50	13.19	2.51e-06
Resolution	1	88	87.60	0.86	0.35
Daylight	1	70	70.00	0.69	0.41
BodyFat %	1	128	128.20	1.27	0.26
Sex:Camera	2	27	13.60	0.14	0.87
Sex:Resolution	2	32	15.80	0.16	0.86
Sex:Daylight	2	17	8.60	0.09	0.92
Camera:Daylight	1	478	478.10	4.72	0.03
Resolution:Daylight	1	147	147.10	1.45	0.23
Sex:BodyFat %	1	39	39.20	0.39	0.53
Camera:BodyFat %	1	59	59.10	0.58	0.45
Resolution:BodyFat%	1	6	6.20	0.06	0.81
Daylight:BodyFat%	1	53	53.10	0.52	0.47
Sex:Camera:Daylight	2	54	27.00	0.27	0.77
Sex:Resolution:Daylight	2	4	2.10	0.02	0.98

Sex:Camera:BodyFat%	1	149	149.10	1.47	0.23
Sex:Resolution:BodyFat%	1	52	51.70	0.51	0.48
Sex:Daylight:BodyFat%	1	23	23.10	0.23	0.63
Camera:Daylight:BodyFat%	1	39	38.60	0.38	0.54
Resolution:Daylight:BodyFat%	1	23	22.90	0.23	0.63
Sex:Camera:Daylight:BodyFat%	1	2	2.40	0.02	0.88
Sex:Resolution:Daylight:BodyFat%	1	53	53.50	0.53	0.47
Camera:Resolution:Daylight:BodyFat%:Sex	2	4	2.10	0.02	0.98
Residuals	582	58946	101.30		

11.1. Imaging Modality and Feature Count

The aim of this study is to determine which imaging modality enables the most feature data to be observed in images of the dorsum of the hand. For analysis to be conducted, feature count data was employed as the dependent variable to represent the quantity of data observed in each image type. Both tables 11 and 12 indicate that there is a highly significant difference observed between camera type and feature count.

When considered independently of resolution and light settings, camera type has the most significant influence on the amount of feature data observed in collected images. The P values resulting from initial ANOVA tests are statistically significant, with P values of <0.001 and 1.28e-6 presented in Tables 11 and 12 respectively. As each camera type captures images at defined resolutions of 0.3MP and/or 9MP, with images being collected under two light settings (daylight ON and daylight OFF), both variables of resolution and lighting were considered during analysis.

Figure 30 represents the total feature count associated with each imaging modality under the test parameters of light setting and/or resolution. From the data columns it can be seen that the greatest total feature count is observed in images captured using the DSLR camera at a resolution of 9 megapixels with the daylight off (9MPdlOFF). The fifth data column represents the lowest total feature count which is observed in images taken using the VeinViewer with the daylight on (VVdlON).

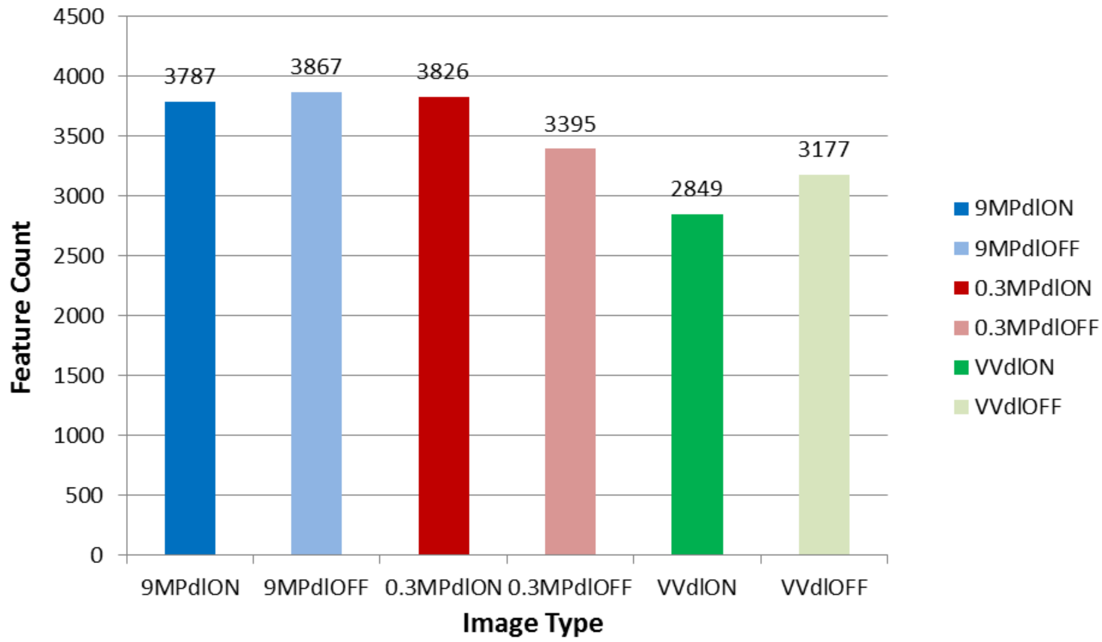


Figure 30. Bar Chart showing the Total feature Count associated with each Imaging Type

Statistical analysis was undertaken to assess the magnitude of the differences observed in Figure 30 between the feature counts recorded for each image type. Table 13 presents the results of this statistical comparison.

Table 13. Table showing the significance of observed differences in Total Feature Count between imaging modalities

Comparison	Difference of Means	t	P	P<0.05
9MPdlON vs. VVdlON	1.41	16.84	<0.001	Yes
9MPdlON vs. VVdlOFF	0.92	10.95	<0.001	Yes
9MPdlON vs. 0.3MPdlOFF	0.59	7.04	<0.001	Yes
9MPdlOFF vs. VVdlON	1.55	18.52	<0.001	Yes
9MPdlOFF vs. VVdlOFF	1.06	12.64	<0.001	Yes
9MPdlOFF vs. 0.3MPdlOFF	0.73	8.73	<0.001	Yes
0.3MPdlON vs. VVdlON	1.47	17.54	<0.001	Yes
0.3MPdlON vs. VVdlOFF	0.98	11.65	<0.001	Yes
0.3MPdlON vs. 0.3MPdlOFF	0.65	7.74	<0.001	Yes
0.3MPdlOFF vs. VVdlON	0.82	9.80	<0.001	Yes
0.3MPdlOFF vs. VVdlOFF	0.33	3.91	<0.001	Yes
VVdlOFF vs. VVdlON	0.49	5.89	<0.001	Yes
9MPdlOFF vs. 9MPdlON	0.14	1.68	0.251	No
9MPdlOFF vs. 0.3MPdlON	0.08	0.98	0.543	No
0.3MPdlON vs. 9MPdlON	0.06	0.70	0.484	No

From Table 13 it can be seen that there is a highly significant difference between the number of features identified in images acquired using the DSLR at all resolutions, under both lighting conditions compared with the VeinViewer images. This is demonstrated by the P value for all comparisons of DSLR images with VeinViewer images being less than 0.001.

With P values greater than 0.05, there is no statistically significant difference between the number of features observed between the following image types;

1. DSLR images of 9MP resolution with the daylight on and daylight off (9MPdlOFF vs. 9MPdlON)
2. DSLR images of 9MP resolution with the daylight off and 0.3MP resolution with the daylight on (9MPdlOFF vs. 0.3MPdlON)
3. DSLR images of 0.3MP resolution with the daylight on and DSLR images of 9MP resolution with the daylight on (0.3MPdlON vs. 9MPdlON)

Table 14 provides a summary of this information, with Y denoting a statistically significant difference between image types, and N indicating that observed differences between total feature counts are not statistically significant.

Table 14. Table showing statistical significance of observed differences in Total Feature Count between image types

	9MPdlON	9MPdlOFF	0.3MPdlON	0.3MPdlOFF	VVdlON	VVdlOFF
9MPdlON		N	N	Y	Y	Y
9MPdlOFF	N		N	Y	Y	Y
0.3MPdlON	N	N		Y	Y	Y
0.3MPdlOFF	Y	Y	Y		Y	Y
VVdlON	Y	Y	Y	Y		Y
VVdlOFF	Y	Y	Y	Y	Y	

To determine the ability of each imaging modality to identify vein patterns, percentage data loss calculations were undertaken. The results of these claculations are presented in Table 15. To determine percentage data loss, the feature count associated with each image type (n) was subtracted from the maximum feature count observed (Max), giving a value (a) which was then divided by the maximum count (a/Max). This figure was then multipliued by 100 and rounded to one decimal place to produce figures of percentage data loss.

Table 15. Percentage Data Loss calculations associated with Total Feature Counts observed using each Imaging Device

Image Type	n. Feature Count	a=Max-n	a/Max	% Data Loss
9MPdlOFF	3867			
0.3MPdlON	3826	41	0.01	1.1
9MPdlON	3787	80	0.02	2.1
0.3MPdlOFF	3395	472	0.12	12.2
VVdlOFF	3177	690	0.18	17.8
VVdlON	2849	1018	0.26	26.3

From the table above the DSLR images are associated with the least percentage data loss. The percentage data losses associated with DSLR images captured at resolutions of 0.3MP and 9MP with the daylight on (0.3MPdlON and 9MPdlON) are 1.1% and 2.1% respectively, with an increased percentage data loss of over 10% for the remianing DSLR images (0.3MPdlOFF). The highest percentage data loses are observed in Veinviewer images, with over a quarter of the feature count data present being lost in images obtained using the Veinviewer with the daylight on (VVdlON).

11.1.1. Resolution

Feature count data obtained for the purposes of comparison was attained from images using each imaging modality under each test condition. The DSLR was utilised to capture images at reolutions of both 9MPand 0.3MP. Images were captured using the same resolution as the VeinViewer (0.3MP) to enable direct comparison of the two devices, with DSLR images obtained at 9MP being utilised to compare the maximum capabilities of the DSLR with both the lowest resolution and with the VeinViewer.

Figure 31 depicts the difference between the average feature counts observed using each imaging device at a resolution of 0.3MP. From the figure it can be seen that images captured using the DSLR (at 0.3MP) contain on average more feature data than those captured using the VeinViewer. This simplifies the trend observed in Figure 30, with all data associated with DSLR images under all test parameters having a greater total feature count than VeinViewer images.

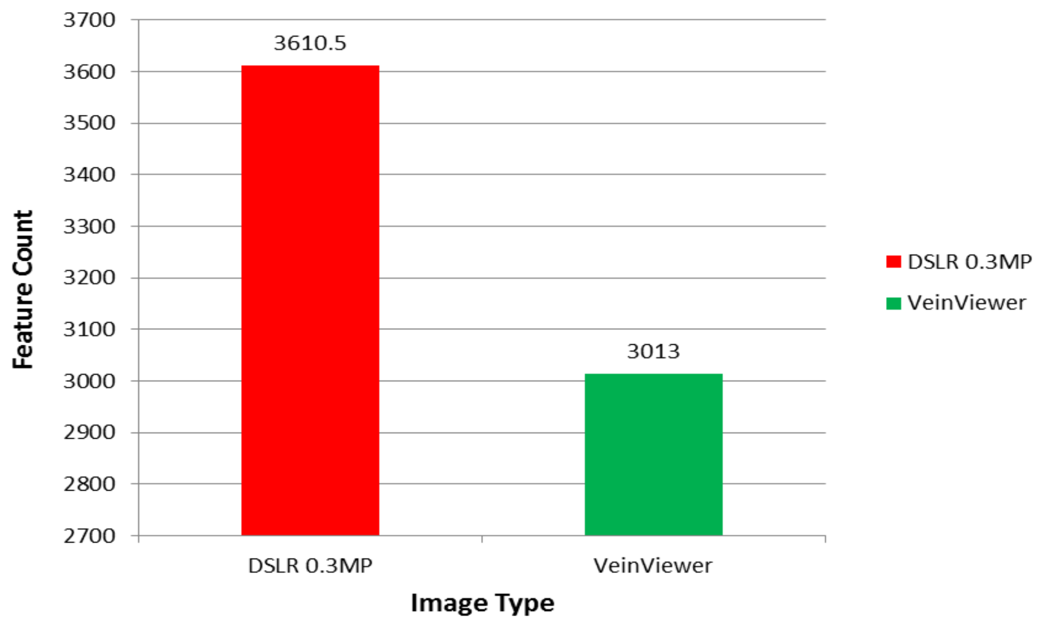


Figure 31. Bar Chart showing average Feature Count associated with each Imaging Device at the same resolution

From Table 13 it can be seen that the difference between 9MPdlON and 9MPdlOFF (columns 1 & 2), and between 9MPdlOFF and 0.3MPdlON (columns 2 & 3) and 0.3MPdlON and 9MPdlON (columns 1 & 3) are not significant. The differences observed between the remaining combinations of DSLR image types are significant, i.e. there is a significant reduction of features recorded in images acquired at 0.3MP with the daylight off.

Feature count data associated with images obtained using the VeinViewer were also analysed. As the VeinViewer is only capable of capturing images with a resolution of 0.3MP, external light setting was tested as the experimental factor. From the associated diagram (Figure 30) it can be seen that VeinViewer images captured with the daylight off contain a greater amount of feature count data than those captured with the daylight on. This difference is highly significant with a P value of less than 0.001 (Table 13).

Direct comparison of DSLR and VeinViewer images obtained using the same resolution (0.3MP) reflect the overall trend in feature count data, with DSLR images containing more information than VeinViewer images, as demonstrated in Figure 30. All differences between feature counts represented in Figure 30 are significantly different, with P values listed in Table 13 as less than 0.001.

When resolution is considered independently of camera type, it is noted that resolution in itself does not have a significant effect on the amount of feature count data observed in each image type. This is presented in Table 12, with resolution having a P value of 0.35.

11.1.2. Lighting

To investigate the effect of external lighting conditions on the amount of information visible in each image type, data associated with images captured in the two lighting conditions (daylight ON and daylight OFF) were considered seperately. The graph below (Figure 32) depicts images captured with the daylight on, and Figure 33 represents images captured with the daylight off.

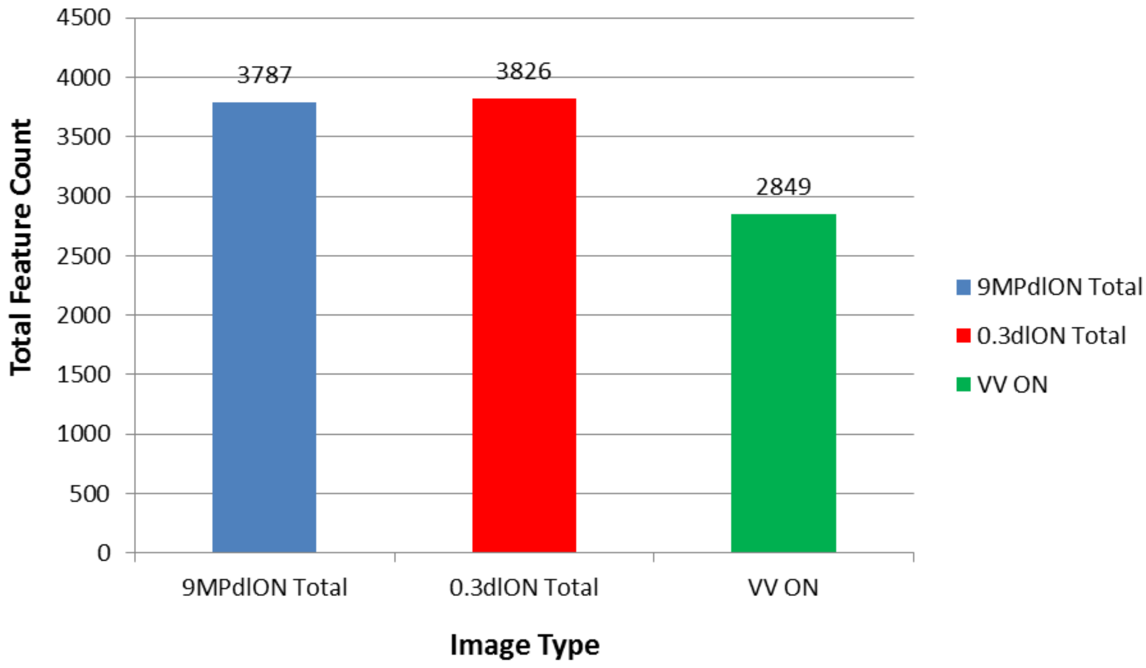


Figure 32. Total Feature Counts associated with Daylight On images

Whilst the differences in total feature count between the VeinViewer images captured with the daylight on and those taken at 9MP and 0.3MP under the same lighting conditions are significant ($P < 0.001$, Table 13), there is no statistically significant difference between the two DSLR image types (9MPdlON and 0.3MPdlON).

In contrast, the differences between all three image types acquired with the daylight off (Figure 33) are statistically significant. This significance is presented in Table 12, with P values associated with all daylight off images being less that 0.001.

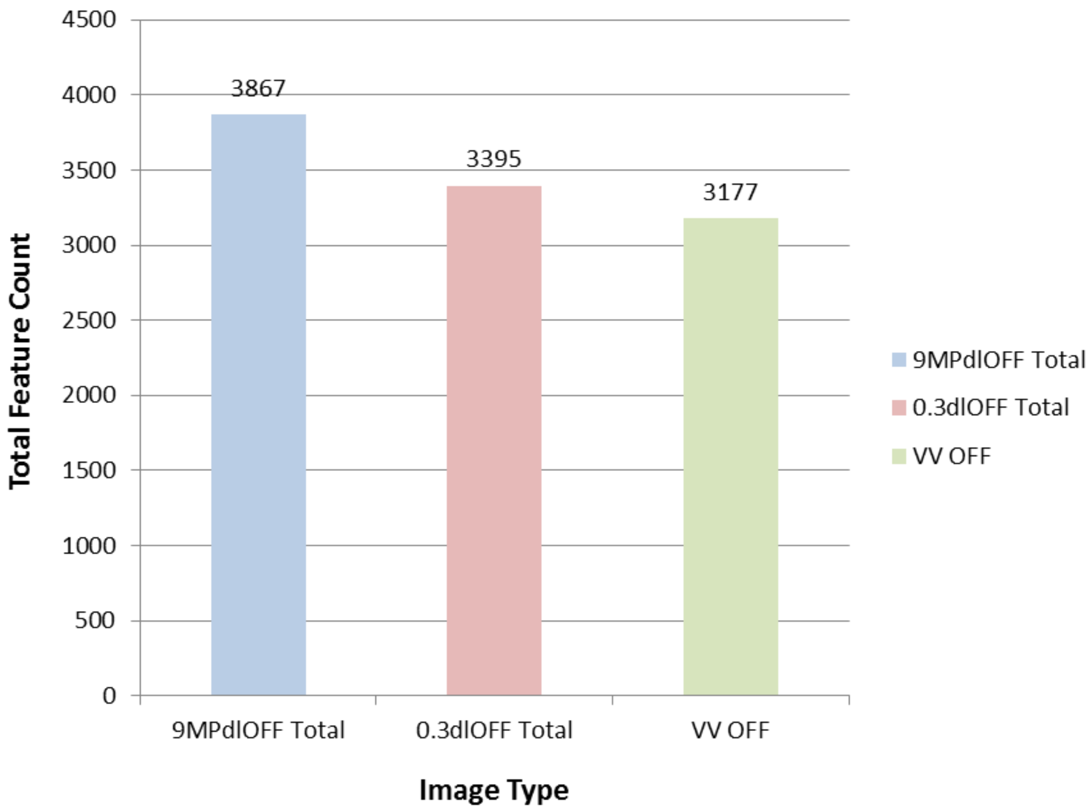


Figure 33. Total Feature Counts associated with Daylight Off images

The ANOVA results presented in Table 12 highlights that lighting does not have a significant influence on the amount of feature count data observed in images. The P value of 0.41 associated with lighting condition (denoted as Daylight in Table 12) represents this lack of significance. In addition, analysis also confirms that the variables of resolution and lighting do not interact with each other to influence feature count (P=0.23).

11.2. Feature Type and Feature Count

As reported in statistical output previously presented in this chapter (Table 11), there is a statistically significant interaction between Feature Type and Feature Count. Figure 34 provides details of the observed frequency of each feature type. Lines were identified most commonly in all image types, with intersections being noted the least.

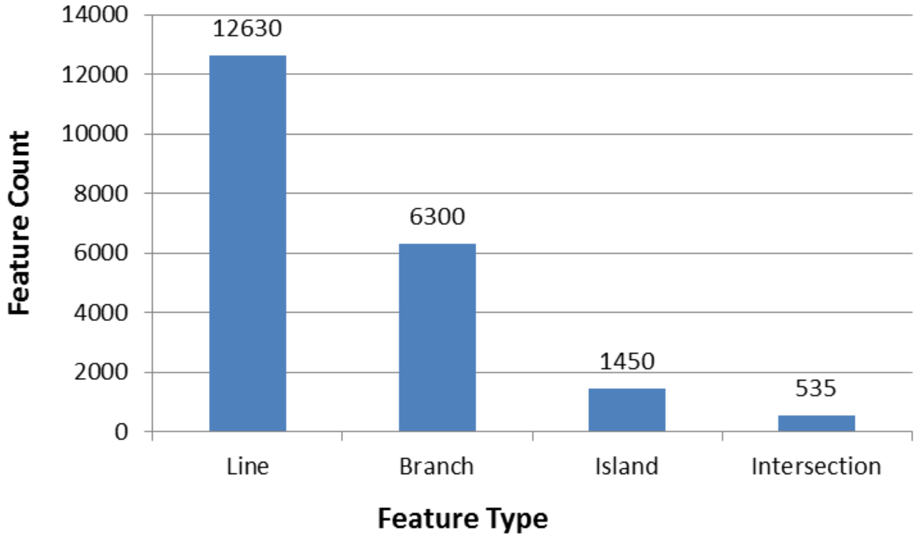


Figure 34. Bar Chart showing the observed frequency of each feature type

To determine the significance of the differences observed between the frequency of feature types observed, a Kruskal-Wallis One Way ANOVA was carried out (Table 16), with subsequent multiple comparison procedure being utilised to isolate the differences between the groups (Table 17). Table 17 summarises the significance of differences observed between the data presented in Figure 34.

Table 16. Table showing frequency of each Feature Type

Group	*N	Missing	Median	25% Confidence	75% Confidence
Line	6	0	2111.50	1937.00	2277.50
Branch	6	0	1077.50	920.75	1170.25
Island	6	0	244.00	170.00	285.25
Intersection	6	0	96.00	70.00	103.25
Significance	*P<0.001*				

To illustrate the differences in feature type frequency, the data displayed in Table 16 is represented graphically in Figure 35 below.

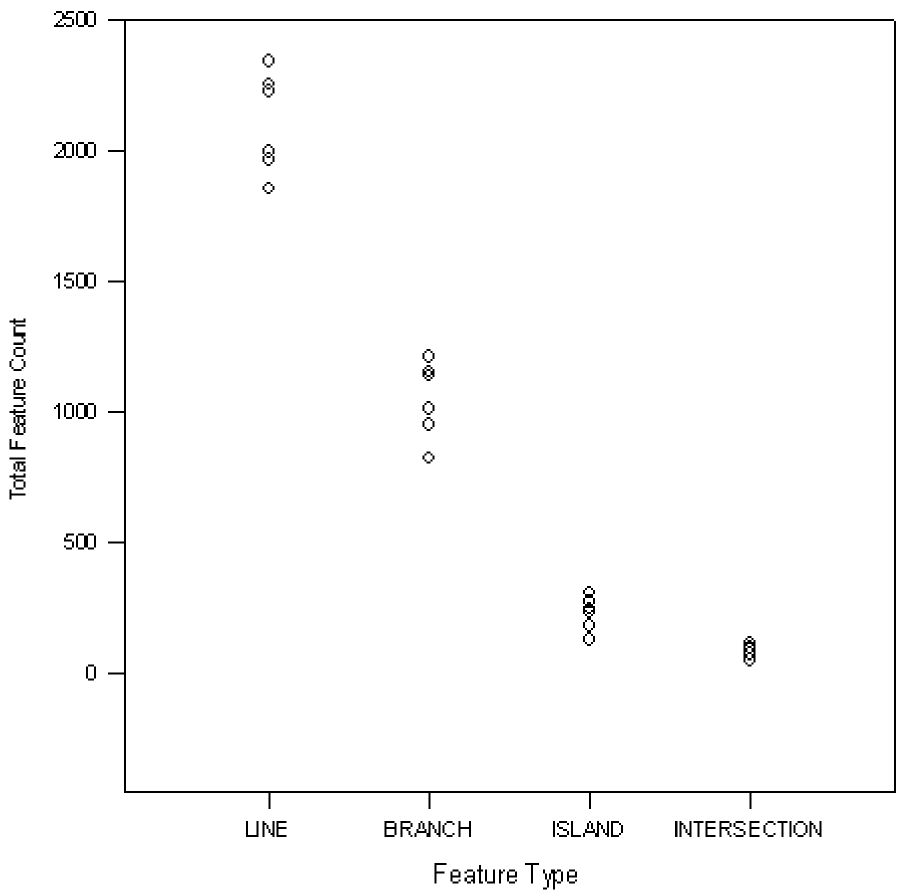


Figure 35. Point Plot showing results showing interaction between Feature Type and frequency

**N calculations; N= 6 image types (4xDSLR and 2xVeinViewer)*
DSLR - 9MPdlON, 9MPdlOFF, 0.3MPdlON, 0.3MPdlOFF
VeinViewer – 0.3MPdlON, 0.3MPdlOFF

Table 17 presents the results of the multiple comparison procedure utilised to isolate the observed differences between the test groups.

Table 17. Results of multiple comparison procedure to isolate differences between frequencies of Feature Types

Comparison	Difference of Means	t	P	P<0.050
Lines vs. Intersections	73.73	22.07	0.001	Yes
Lines vs. Islands	68.13	20.39	0.001	Yes
Lines vs. Branches	38.53	11.53	0.006	Yes
Branches vs. Intersections	35.19	10.54	0.005	Yes
Branches vs. Islands	29.60	8.86	0.006	Yes
Islands vs. Intersections	5.59	1.67	0.193	No

Table 17 shows that there is a statistically significant difference between the total frequency of Lines and Intersections, Lines and Islands, Lines and Branches, Branches and Intersections, and Branches and Islands. There is no significant difference between Islands and Intersections. These results can be seen in Figure 35, as the point plots for each feature type combination except for Islands and Intersections do not overlap.

In addition to the three primary experimental factors, available data on Body Fat Percentage and Sex was utilised to conduct analysis into the effect of these variables on observed feature counts.

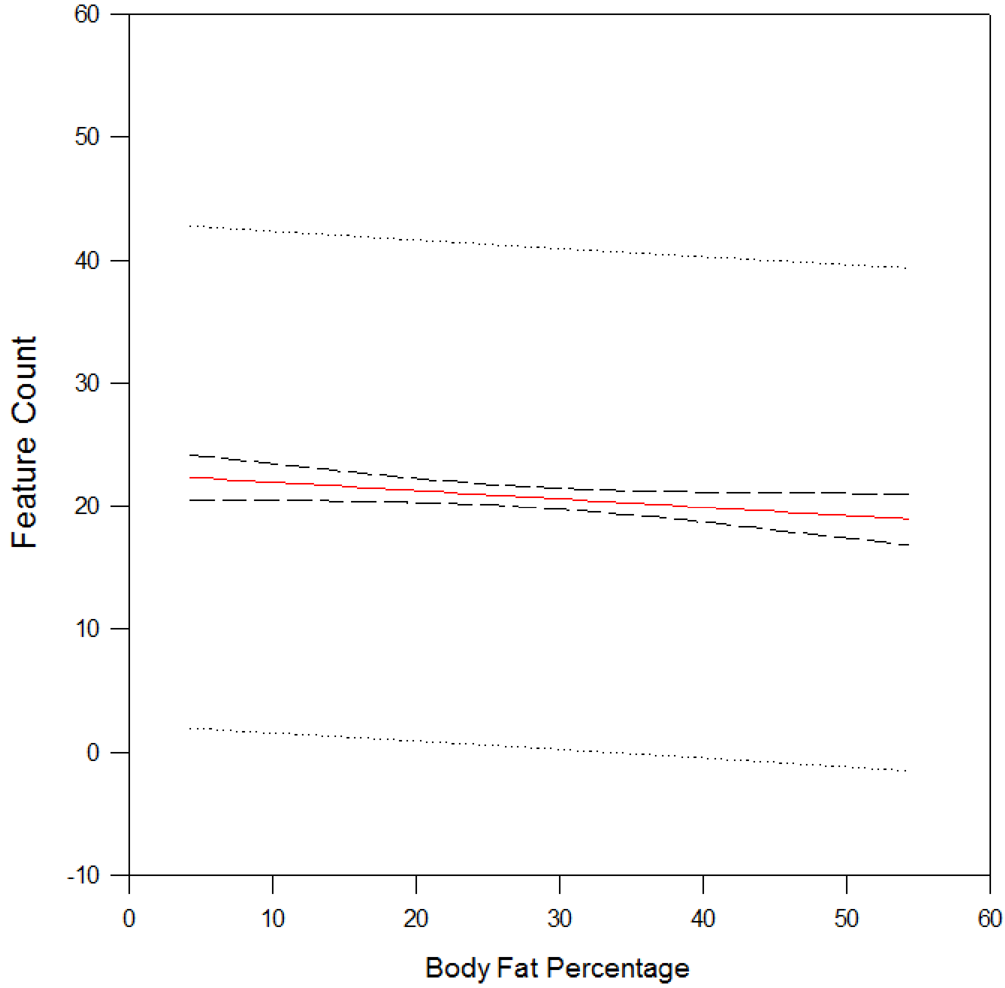
11.3 Body Fat Percentage and Feature Count

A simple linear regression was undertaken to determine the correlation between body fat percentage of the left and right arms of each participant and feature count. The linear equation utilised to conduct analysis is Total Feature Count = 22.640 – (0.0684 * Body Fat %). The figures utilised for this equation are calculated by SigmaPlot and are listed in Table 18.

Table 18. Linear regression calculation determining the correlation between body fat percentage and feature count

	Coefficient	Std. Error	t	P
Constant	22.640	1.078	20.999	<0.001
Body Fat %	-0.0684	0.036	-10877	0.061

The resultant R value of 0.0768 produced by this calculation indicates that there is no significant correlation between body fat percentage and feature count. This correlation is displayed in Figure 36. The linear regression graph indicates that as body fat percentage increases, the feature count decreases slightly. The P value of 0.061 demonstrates that this observed relationship represented by the regression line is not statistically significant. This result reflects that obtained from analysis of variance presented in Table 12, with body fat percentage having an associated P value of 0.2611.



Legend:

Prediction bands – 95% of all data points fall between these lines

Confidence Limits – 95% confidence that the true regression line falls between these two lines

Regression Line – line showing the correlation between X and Y values

Figure 36. Linear regression graph demonstrating the correlation between body fat percentage and feature count

11.4. Sex and Feature Count

Statistical results presented in Table 12 show a highly significant difference between the amount of feature count data observed between the sexes. The P value associated with this calculation is 2.51e-06, with only Camera Type being more highly significant at 1.28e-06. A One Way ANOVA was used to explore the observed differences between sex and feature count. The results of this test are displayed in Table 19.

Table 19. One Way ANOVA Summary of Sex and Feature Count

Group	**N**	**Missing**	**Median**	**Lower Quartile (25%)**	**Upper Quartile (75%)**
Female	372	0	18.5	12.0	25.0
Male	223	0	23.0	15.0	32.0
Significance	P<0.001				

The box plot shown in Figure 37 provides graphical representation of these results.

**N calculations;*
Female; N=372 female participants
Male; N=223male participants

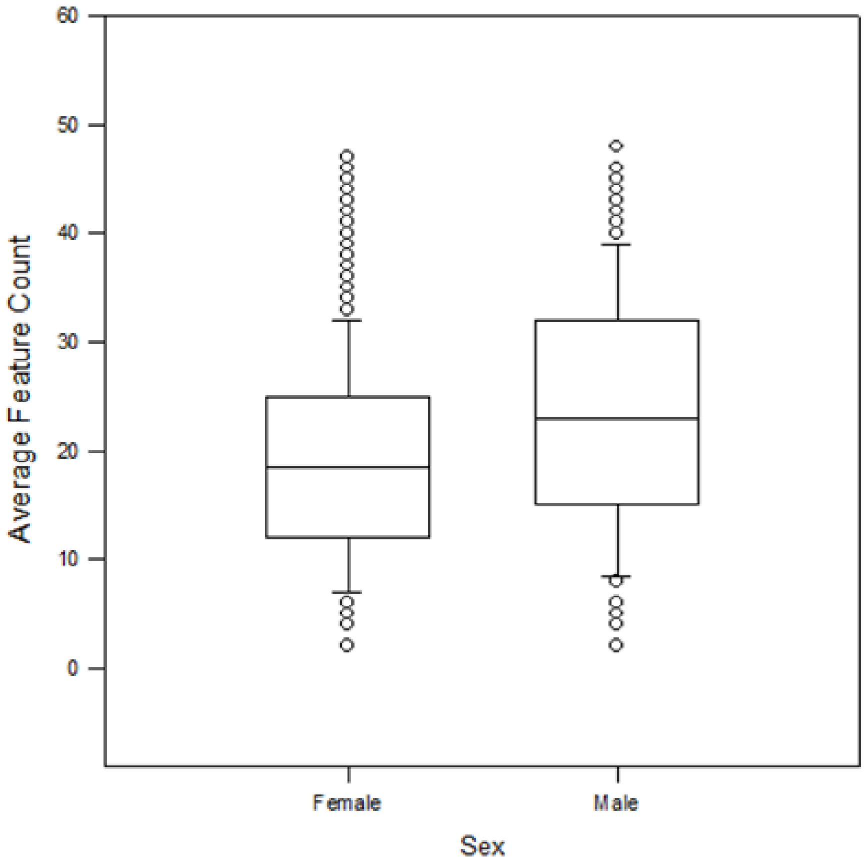


Figure 37. Box Plot showing average Feature Count by Sex

From the box plot it can be seen that the male median value (23) is slightly higher than that of the female group (18.5). The upper quartile and whisker of the male group noticeably exceed that of the female group, confirming previous results which have demonstrated that male images have a higher feature count. The Female group has a higher number of individuals displaying greater feature counts than average. N for this residuals group is 15, whereas only 8 individuals reside as maximum outliers in the Male group (indicated by the upper whiskers). This greater number of residuals in the female group explains the variation in line shape between Males and Females in Figure 40. The resultant P value for this calculation is less than 0.001

(P<0.001) indicating a highly significant difference between the feature counts observed in each group.

As these statistical tests demonstrate significant differences between the factors of Sex and Feature count, and Body Fat Percentage and Feature Count, further analysis was undertaken to determine the interaction of these variables with the experimental factors and each other.

11.5. Interactions between Experimental Factors

Testing the hypotheses associated with the three way ANOVA of no differences between the experimental groups, is unable to determine which groups are different or the magnitude of observed differences (Systat Software Inc, 2011). The Multiple Comparison option was enabled to isolate said differences when the 3 way ANOVA detected a significant difference between groups. As it was desired to test the difference between each group, the All Pairwise Comparisons test was selected.

As the ANOVA produced resultant P values of less than 0.05 for all three factors tested, the Multiple Comparisons feature was initialised, with all three factors selected for comparison. The Holm-Sidak test was suggested by SigmaPlot for multiple comparison analysis due to its increased power when compared to alternative methods. The multi comparison process utilised to isolate differences, enabled analysis of the interactions between the experimental factors. Table 20 displays the results obtained from this analysis.

Table 20. Summary report of Multiple Comparison analysis to determine the interactions between the listed features

Factor	**DF**	**SS**	**MF**	**F**	**P**
Indiv:Feat	495	12269	25	2.22	0.000505
Indiv:ImageType	825	7281	9	0.78	0.900702
Feat:ImageType	15	623	42	3.63	0.000335
Indiv:Feat:ImageType	2475	5716	2	0.21	1.000000
Residuals	2475	*5785.53*	*2.34*		

Please note that abbreviations have been used for the experimental factors; Individual (Indiv), Feature Type (Feat) and Imaging Modality (ImageType).

The multiple comparison summary in Table 20 indicates that there are highly significant differences between the interaction of individual and feature type (Indiv:Feat), and the interaction between feature type and modality/resolution (Feat:ImageType).

As the P values are greater than 0.05 for the interactions between Individual and modality/resolution (Indiv:ImageType), as well as for the three way interaction of individual, feature type and modality/resolution (Indiv:Feat:ImageType), it can be concluded that there is no significant difference within these interactions.

11.5.1. Feature Type and Imaging Modality

The statistically significant interaction between feature type and imaging modality (Feat:ImageType) as highlighted in the summary report of multiple comparison analysis of experimental factors (Table 20) is depicted in Figure 38.

Figure 38 shows a graphical representation of the average number of each feature type visible in images taken with the two different imaging modalities under each test condition of resolution and lighting. From the figure it is noted that intersections are the least frequently occurring feature type in images taken with each modality, with lines being the most frequently occurring, which follows the trend identified in Figure 39, representing the frequency of each feature type.

Results obtained from tracing and the subsequent recording of features present in each image type show that images acquired using the DSLR camera consistently identified a greater quantity of features than those acquired using the VeinViewer device. The greatest number of line and intersection features of the vein patterns were visualised in DSLR images captured at 9MP with the daylight off (9MPdlOFF), depicted by the red data line in Figure 38. When observing branch and island features of the vein patterns, images acquired using the DSLR camera at 0.3MP with the daylight on (0.3MPdlON) achieved the highest counts. It must be noted however that the difference between 0.3MPdlON images and 9MPdlOFF images is not statistically significant (see Table 12). Conversely, the least amount of all features identified in images were those captured using the VeinViewer with the daylight on.

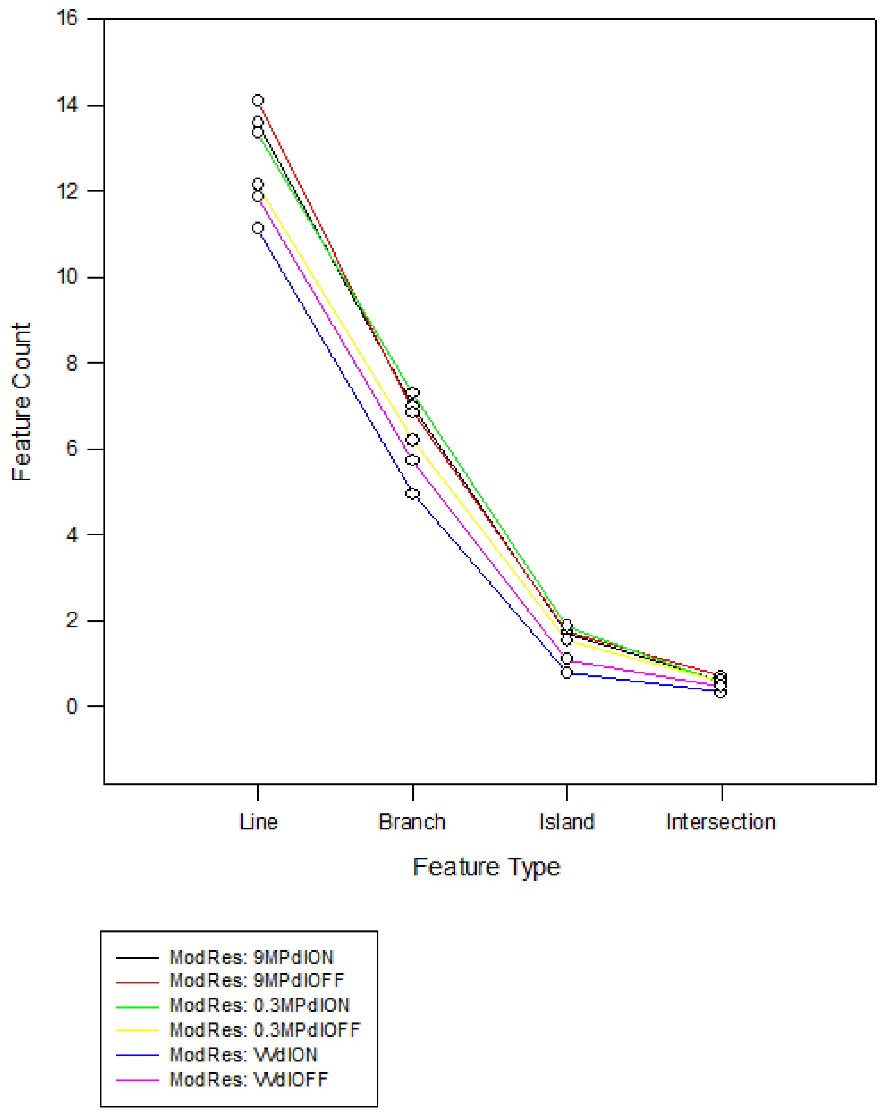


Figure 38. Graph showing the interaction of Feature Type and Imaging Device

The folllowing chart presents this information in the form of a bar chart, with the frequencies of each feature type grouped according to image type.

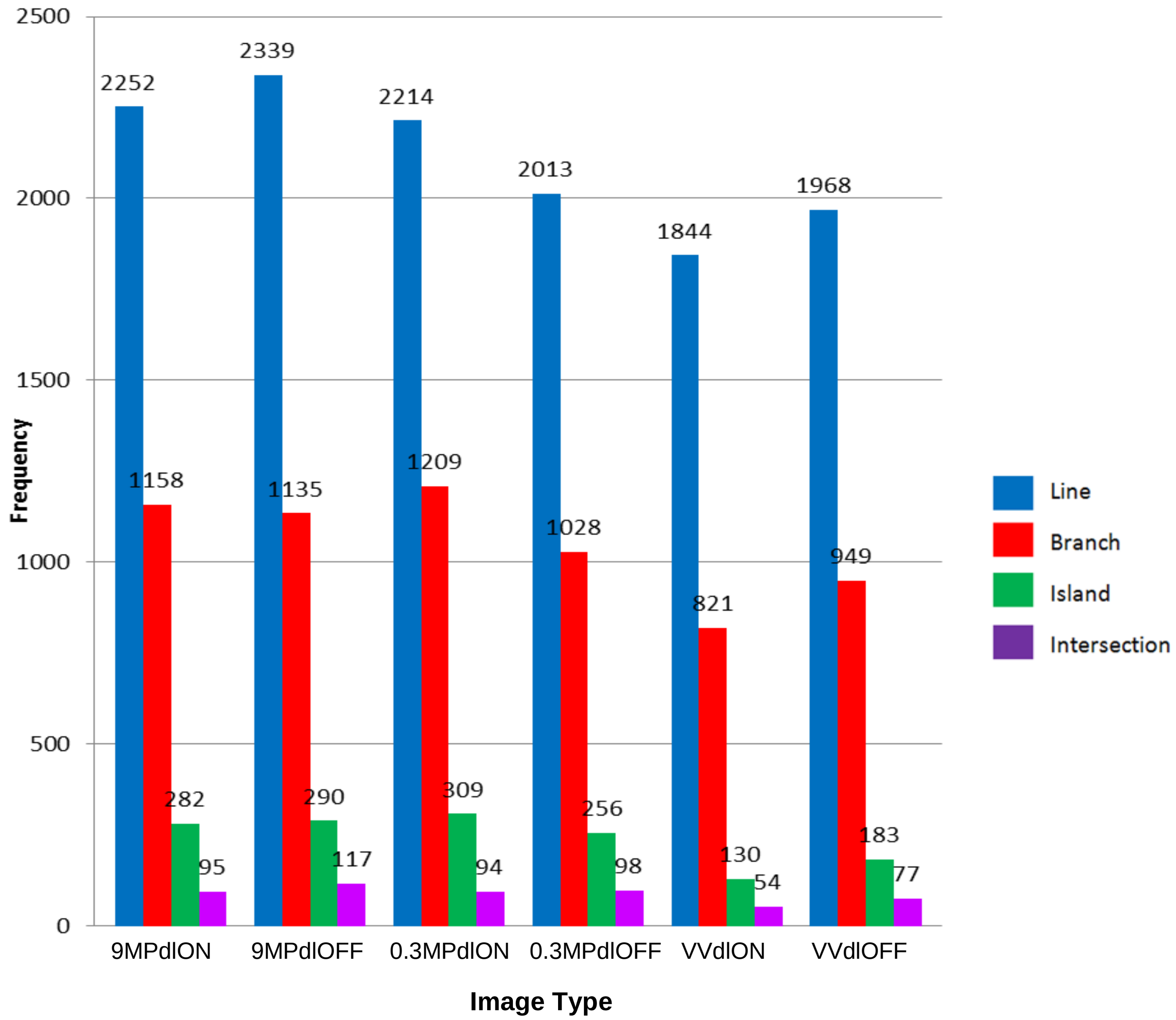


Figure 39. Bar chart showing frequency of each Feature Type observed in each Image Type

Again the pattern reflects that of Figure 34, with the prevelance of each feature type remaining constant in each image type. As such, it can be noted that Imaging Device does not influence the Feature Types observed in images.

To determine the power of each imaging modality in discerning individual feature types, calculations of percentage data loss were undertaken. To determine percentage data loss, the feature count associated with each image type (n) was subtracted from the maximum feature count associated with the feature type in question (Max), giving a value (a) which was then divided by the maximum count (a/Max). This figure was then multipliued by 100 and rounded to one decimal place to produce figures of percentage data loss. The tables below are listed in order of the most to least commonly occuring features (Lines -> Intersections).

As the average frequency of each feature type varies, the discriminant power of each feature type differs. Consequentially, in the least commonly occurring feature type (intersections), failure to identify this feature carries greater weight. For example, in an individual possessing two intersections, failure to identify one of these two features would result in a percentage data loss figure of 50%, however when considering the feature type Lines (the most commonly occurring) failure to identify one of twenty would result in a much lower figure of 5% data loss.

Table 21 presents percentage data loss calculations for the number of lines visible in each image type. As can be seen from Figure 39, the maximum feature count observed for the feature Lines is 9MPdlOFF. For images obtained at 9MPdlON and 0.3MPdlon, the percentage data loss is less that ten percent, being 3.7% and 5.3% respectively. The percentage data loss associated with images acquired with the DSLR and VeinViewer at 0.3MP with the daylight off are 13.9% and 15.9% respectively. The greatest percentage data loss (21.2%) is observed in images captured with the VeinViewer with the daylight on (VVdlON).

Table 21. Percentage Data Loss calculations for Lines

Image Type	n. Lines	a=Max-n	a/Max	% Data Loss
9MPdlOFF	2339			
9MPdlON	2252	87	0.04	3.7
0.3MPdlON	2214	125	0.05	5.3
0.3MPdlOFF	2013	326	0.14	13.9
VVdlOFF	1968	371	0.16	15.9
VVdlON	1844	495	0.21	21.2

Percentage data loss claculations for the number of branches observed in each image type are presented in Table 22. In contrast to similar calculations for Line features (Table 21), the greatest number of Branches are observed in images captured with the DSLR at a resolution of 0.3MP with the daylight on (0.3MPdlON). A greater percentage data loss is observed between the maximum and minimum counts for Branches (32.1%) than observed for Lines (21.2%). As observed previously (Table 21), VeinViewer images are associated with the greatest percentage data losses of 21.5% and 32.1%.

Table 22. Percentage Data Loss calculations for Branches

Image Type	n. Branches	a=Max-n	a/Max	% Data Loss
0.3MPdlON	1209			
9MPdlON	1158	51	0.04	4.2
9MPdlOFF	1135	74	0.06	6.1
0.3MPdlOFF	1028	181	0.15	15
VVdlOFF	949	260	0.22	21.5
VVdlON	821	388	0.32	32.1

Calculations of percentage data loss associated with Islands are presented in Table 23. As observed with analysis of Lines and Branches, VeinViewer images again presented the highest observed percentage data losses associated with Islands. These VeinViewer data losses follow the same pattern as before, with VVdlON images having a higher percentage data loss (57.9%) than images captured with the VeinViewer with the daylight off (40.1%).

Table 23. Percentage Data Loss calculations for Islands

Image Type	n. Islands	a=Max-n	a/Max	% Data Loss
0.3MPdlON	309			
9MPdlOFF	290	19	0.06	6.1
9MPdlON	282	27	0.09	8.7
0.3MPdlOFF	256	53	0.17	17.2
VVdlOFF	183	126	0.41	40.1
VVdlON	130	179	0.58	57.9

Table 24 presents percentage data loss claculations associated with the number of Intersections observed in each image type. As observed in previous percentage data loss calculations associated with each feature type, images captured using the VeinViewer camera display the greatest percentage data loss for Intersections. Images captured using the DSLR at a resolution of 9MP with the daylight on (9MPdlON) display the greatest number of Intersections. This is similar to data loss calculations associated with Lines (Table 20) which also attribute the greatest feature count to 9MPdlON images.

Table 24. Percentage Data Loss calculations for Intersections

Image Type	n. Intersections	a=Max-N	a/Max	% Data Loss
9MPdlOFF	117			
0.3MPdlOFF	98	19	0.16	16.2
9MPdlON	95	22	0.19	18.8
0.3MPdlON	94	23	0.20	19.7
VVdlOFF	77	40	0.34	34.2
VVdlON	54	63	0.54	53.8

From these calculations of percentage data loss, it can be seen that the DSLR camera is capable of visualising more vein pattern information than the VeinViewer, as maximum feature counts and the lowest values for percentage data loss for each feature type are consistently associated with DSLR images. Conversely, the greatest percentage data losses for all feature types are associated with VeinViewer images, with VVdlON images accounting for the greatest overall percentage data losses across the board.

11.5.2. Imaging Modality and Sex

A two way ANOVA was conducted to determine if sex influenced the feature count data observed in images captured using each modality. From Table 25 it can be seen that there is a highly significant difference between sex and feature count and between image type and feature count (with P values of less than 0.001).

Table 25. Two Way ANOVA summary for Image Type and Sex

Factor	**DF**	**SS**	**MF**	**F**	**P**
Image Type	5	5493.78	1098.76	10.39	<0.001
Sex	1	4437.75	4437.75	41.95	<0.001
Image Type x Sex	5	73.71	14.74	0.14	0.983
Residual	*984*	*104106.06*	*105.80*		
Total	*995*	*114101.90*	*114.68*		

The interaction between imaging type and sex demonstrates that there is no significant interaction between these two factors (P = 0.983), with observed differences between sex not being due to the influence of image type. This relationship is shown in Figure 40.

From the results presented in Table 25, it can be stated that whilst both imaging modality and sex influence feature count, when combined they have no significant influence. This relationship may be attributed to the uneven distribution of sex across the test groups, with the sample population including a greater number of female participants.

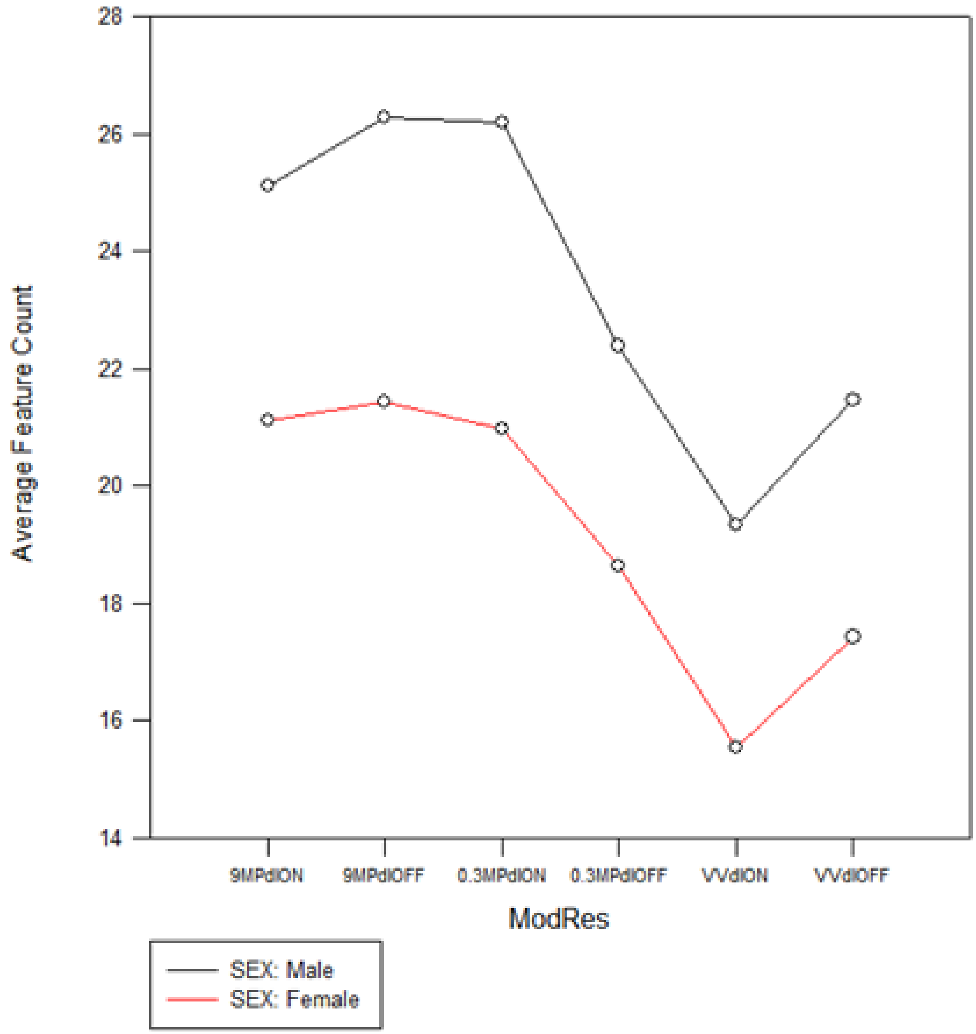


Figure 40. Graph showing relationship between Imaging Modality and Sex

Figure 40 represents the greater feature counts observed in all images captured from male participants with each modality configuration (Camera) when compared to female images. The line representing male participants follows the observations of Figure 30, showing total feature count associated with each image type. The female line varies slightly from this trend, with 9MPdlON images preceding 0.3MPdlON images, however this may be explained by a greater number of outliers in this group (represented by residuals in Figure 37).

These results are supported by the previous analysis presented in Table 12, with Sex and Camera both having a significant effect on feature count, with their interaction (denoted as Sex:Camera) having a corresponding P value of 0.874.

11.5.3. Imaging Modality and Body Fat Percentage

Analysis was performed to test the relationship between body fat percentage and imaging modality. From the Table 26 it is evident that there is no significant difference between body fat percentage and imaging modality. The P value of 1.00 emphasises this fact. Previous statistical analysis (Table 12) highlights that Body Fat Percentage and Imaging Modality do not interact to influence feature count.

Table 26. Table showing results from analysis of the factors Body Fat Percentage and Imaging Modality

Group	N	Missing	Median	Lower Quartile (25%)	Upper Quartile (75%)
9MPdlON	104	0	26.7	17.00	35.575
9MPdlOFF	104	0	26.5	17.60	35.700
0.3MPdlON	104	0	26.9	17.60	35.700
0.3MPdlOFF	104	0	26.5	17.60	35.700
VVdlON	104	0	26.9	17.60	35.7000
VVdloff	104	0	26.5	17.60	35.700
Significance	P=1.000				

Figure 41 provides a graphical representation of this data. The standardised appearance of the boxes and associated data bars reinforces the lack of statistical difference between the two factors.

**N calculations;*
N= 104. 52 participants consented to having their body fat percentage measured.
Measurements were taken of the left and right hands; 52 left and 52 right = 104

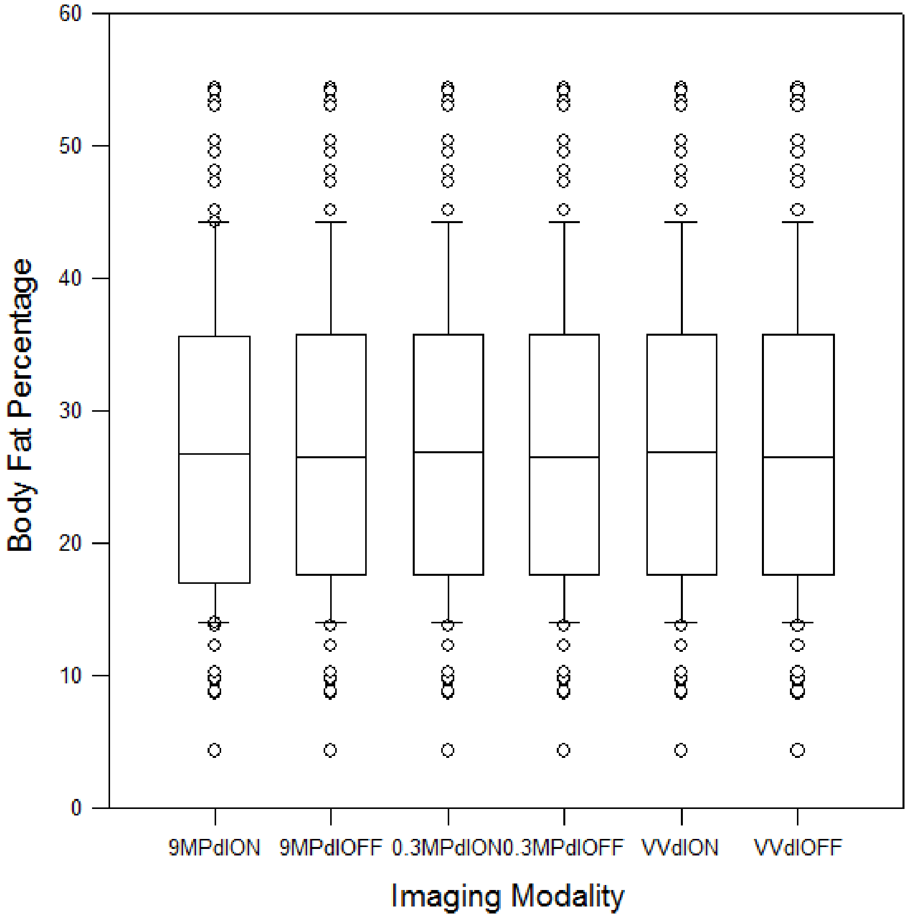


Figure 41. Box Plot summarising calculation of Body Fat Percentage and Imaging Modality

11.5.4. Body Fat Percentage and Feature Type

Statistical analysis was undertaken to determine if there is a significant relationship between the type of feature observed in images and the factors of Imaging Device, Sex and Body Fat Percentage.

Further analysis was undertaken to examine if body fat percentage had an influence on the type of features observed in images of vein patterns (Table 27).

Table 27. Table showing results of analysis for the variables Feature Type and Body Fat Percentage

Group	**N**	**Missing**	**Median**	**Lower Quartile (25%)**	**Upper Quartile (75%)**
Branch	104	0	26.7	17.7	35.575
Intersection	104	0	26.7	17.7	35.575
Island	104	0	26.7	17.7	35.575
Line	104	0	26.7	17.7	35.575
Significance	P = 1.000				

The P value of 1.000 indicates that the differences in median values amongst the treatment groups (feature type and body fat percentage) are not great enough to discount random sampling variability as the source of any observed differences. Figure 42 demonstrates that the observed feature types are not influence by the percentage of body fat of a subject.

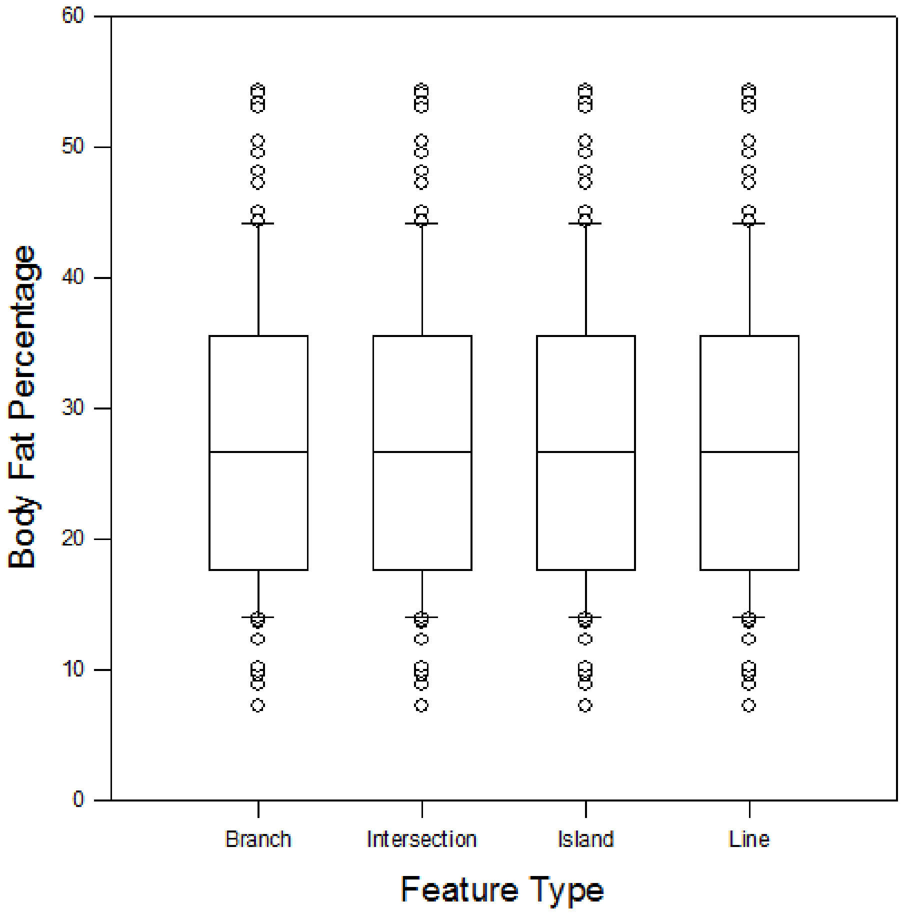


Figure 42. Box Plot showing calculation results for the factors Body Fat Percentage and Feature Type

11.5.5. Sex and Feature Type

The relationship between sex and feature type was investigated to establish any significant trends. The frequency of each feature type observed per sex was firstly established, with subsequent analysis undertaken to determine the significance of any observed differences. Figure 43 depicts the average frequency of each feature type per sex.

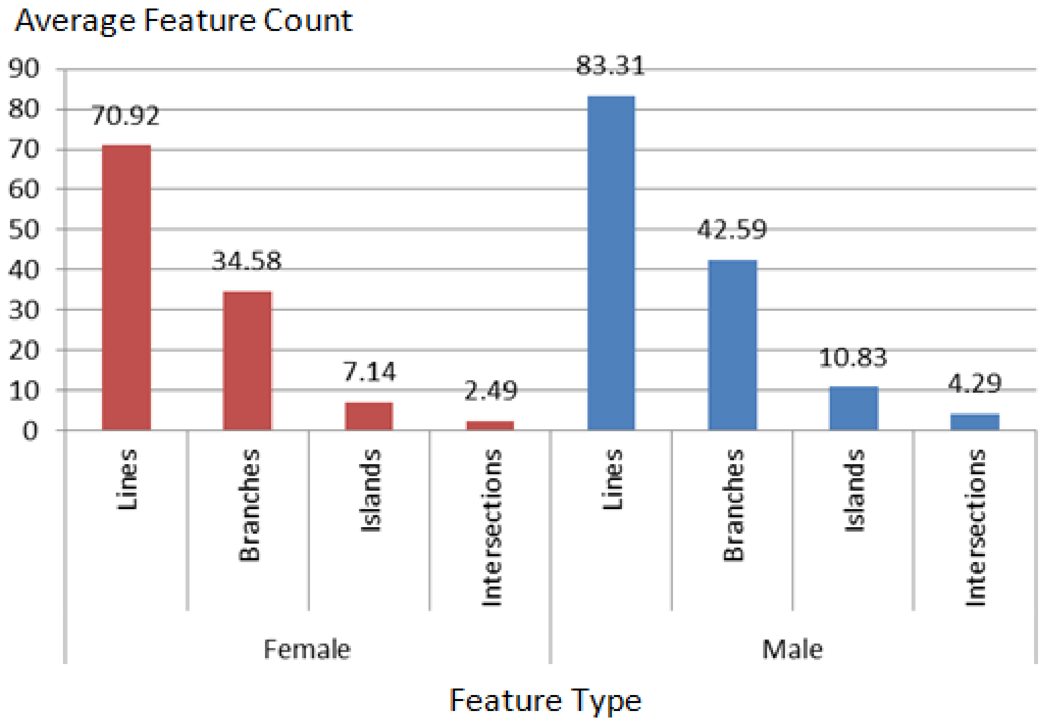


Figure 43. Bar Chart showing the average frequency of each Feature Type per Sex

Figure 43 reflects previous findings with regards to average feature counts per sex (Figure 37), with males displaying greater average feature counts than females. This statement is true for all feature types.

A two way ANOVA was undertaken to determine the effect of sex on the frequency of observed feature types. The results of this statistical test are described below with a summary presented in Table 28.

With a P value of 0.071, it can be stated that the difference in mean values (between the sexes) is not great enough to exclude the possibility that the difference is due to random sampling variablity after allowing for the effects of differences in feature type. The difference in mean values among different levels of feature type is greater than would be expected by chance alone after allowing for effects in differences of sex. With a P value of less than 0.001, this difference is staistically significant. From these results it can be concluded that sex does not influence the type of features observed in images. This finding is clearly represented by Figure 43, showing the frequency of each feature type follows the same pattern for each sex, with Lines occuring most frequently, and Intersections least.

Table 28. Two Way ANOVA of Sex and Feature Type

Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Sex	1	83.79	83.79	7.51	0.0710
Feature	3	6853.89	2284.63	204.73	<0.001
Residual	3	33.48	11.16		
Total	7	6971.16	995.88		

The statistics obtained from the experimental data collected during this research which are presented in this chapter will be discussed in the following section.

12. Discussion

The results obtained from statistical analysis provided in the previous chapter will be discussed in detail in relation to current literature and research, with the aim of relating these outcomes to the objectives of this study.

As the primary aim of this study is to determine which imaging modality has greater utility in vein pattern analysis for the purposes of forensic human identification, the methodology and data collection procedure were designed on the basis of parameters which would best explore this research question.

The methodology of this study was designed to quantify the amount of information visible in vein pattern images of individuals acquired using two infrared imaging modalities; a VeinViewer and a DSLR camera fitted with an IR filter. In terms of biometric analysis for identification purposes, it is reasonable to propose that the more information that is visible for analysis, the greater the probability of correct identification.

Feature count data was utilised to quantify the amount of information that could be observed in the vein pattern images associated with each imaging modality.

12.1. Discussion of initial statistics

Three way analysis of variance (ANOVA) was undertaken to determine if feature count was influenced by any of the three test parameters present in the study; Individual, Feature Type, and Imaging Modality. The results of the ANOVA indicated that there was a highly significant difference ($P<0.001$) between all 3 variables (Table 11).

12.1.1. Individual

With regards to current literature on vein pattern analysis for use in biometric technologies, it has been cited that no two individuals share the same vein pattern, that is, vein patterns are unique to individuals in the same manner as fingerprints are considered unique identifying features (Wang *et al*., 2006; Wilson, 2010; Lin and Fan, 2004). The ANOVA results citing a statistically significant difference between feature count and individual support these findings (Table 11). It is noted that feature count alone is not adequate for comparison analysis, but rather it is the frequency of each individual feature type which enables discriminant comparison analysis to be undertaken. This proposed uniqueness leads to vein patterns being a viable anatomical feature for biometric analysis (Jain *et al.*, 2011).

12.1.2. Feature Type

There is a dearth of literature related to research quantifying the prevalence of different feature types in vein patterns. Biometric systems based upon vein pattern analysis utilise the entire vein pattern visible in the region of interest, with no consideration of the discriminant power of individual features. Initial analysis indicated that there was a significant difference between Feature Type and feature count, with comparison analysis being undertaken to explore the magnitude of differences between feature count and each individual Feature Type. From comparison analysis conducted during this study, it is noted that lines are the most commonly occurring feature, followed by branches, then islands, with intersections being the least commonly observed feature type in the subject population of this study. It is noted that the difference in frequency between Islands and Intersections is not statistically significant. This finding corroborates results of a similar study by Meadows (2011).

12.1.3. Imaging Modality

The significant difference reported between Imaging Modality (denoted as Image Type or Camera during statistical analysis) and feature count is of paramount importance with regards to the primary objective of this study; to assess if there is a significant difference between the amount of information visible in vein pattern images acquired using two imaging modalities (DSLR and VeinViewer).

Total feature count data associated with each image type indicate that DSLR images contained more information than VeinViewer images. Analysis of the average feature count of images acquired using each imaging modality simplify this observed trend, with DSLR images on average containing greater feature counts than VeinViewer.

Resolution

The primary objective of this study was to perform a direct comparison between the amount of vein pattern information visible in images acquired using a DSLR camera and a VeinViewer imaging device. The VeinViewer has a resolution of 0.3 mega pixels (MP) whilst the DSLR has the capability to capture images at 5 different resolution settings (0.3MP, 2MP, 3MP, 5MP, and 9MP). The 0.3MP setting of the DSLR was utilised for direct comparison with the VeinViewer, with the 9MP setting being used to compare the maximum imaging capabilities of the DSLR to the

VeinViewer. Megapixels are the image sensing capacity of a digital imaging device (Schurman, 2014). The resolution of a digital imaging device is determined by the number of pixels, with a higher number of megapixels equating to a higher resolution of images. It is anticipated that the higher the resolution of an image, the more detail will be visible. On this premise, it can be assumed that images captured at 9MP will have a higher feature count than those captured at 0.3MP.

In contradiction to this assumption, values obtained for a comparison of images captured with the DSLR at 9MP with the daylight off (9MPdlOFF) and 0.3MP with the daylight on (0.3MPdlON), and those of 0.3MP (0.3MPdlON) and 9MP both with the daylight on (9MPdlON), were greater than the threshold of statistical significance of 0.05 (being 0.543 and 0.484 respectively) indicating that there is no significant difference between the amount of detail visible in each of the listed image types. Whilst the first comparison set (9MPdlOFF vs. 0.3MPdlON) may possibly be explained by the opposite lighting conditions, the imaging modalities in second comparison (0.3MPdlON vs. 9MPdlON) were subject to the same lighting conditions (daylight on). Results obtained from ANOVA calculations confirm that resolution does not have a significant influence on the amount of feature count data observed in images obtained for the purposes of this study (P=0.3529, Table 12).

Lighting Conditions

The contrasting lighting conditions (daylight off and daylight on) employed during the data acquisition phase of this study were in place to assess the influence of lighting conditions on the amount of information visible in IR pictures of vein patterns in the dorsum of the hand. The VeinViewer has an inbuilt IR illumination source which was running during the entire data collection process, therefore all images captured (both DSLR and VeinViewer) were acquired under the same IR illumination. A daylight lamp was employed to provide contrasting external lighting conditions during data collection.

When considered independently, the lighting conditions employed when acquiring images is not significant with regards to the amount of data which can be seen ($P=0.461$). With regards to the insignificant P value (0.251) describing the relationship between images captured using the DSLR camera at 9MP with the daylight off (9MPdlOFF) and 9MP with the daylight on (9MPdlON), it can be hypothesized that images captured at a resolution of 9MP by the DSLR camera are the most resistant to changes in lighting conditions. Following this hypothesis, it may be suggested that images acquired by the DSLR camera at a resolution of 9MP are the most consistent in terms of observable feature count information.

Direct Comparison analysis undertaken between DSLR images of 0.3MP resolution under the two differing lighting conditions (0.3MPdlON and 0.3MPdlOFF) indicate that this variable has a significant impact on the ability to observe vein pattern information ($P<0.001$) in images acquired at a resolution of 0.3MP. The same can be said for the VeinViewer, with a significant difference observed between the feature counts of images captured with the daylight on and off. These results indicate that IR images captured at a resolution of 0.3MP may be sensitive to changes in external lighting conditions.

In addition to the test parameters listed previously, analysis was also conducted to determine if the factors Sex and Body Fat percentage influenced the amount of vein pattern information visible in images captured using each modality.

12.1.4. Sex

Analysis demonstrated that Sex has a significant influence on the feature count frequency ($P<0.001$). Images of male participants were consistently observed to contain greater average frequency of feature types than images of female participants.

The number of individual feature types associated with images of male participants follows the general trend of total feature counts associated with each image type as identified previously. The data collected for female participants varies slightly from this trend, with 0.3MPdlON images preceding 9MPdlON images in terms of feature count frequency. This anomaly can be explained by the greater number of outliers present in the female group. A great amount of literature is dedicated to the influence of sex on body fat percentage, as a result sex must be considered in association with body fat percentage. The output obtained from ANOVA tests indicate that whilst Sex is highly significant with regards to feature count ($P=2.51e\text{-}06$), when the interaction between Sex and Body Fat Percentage is examined, there is no significant influence on feature count data ($P=0.5343$).

12.1.5. Body Fat Percentage

Linear regression analysis demonstrated a negligible relationship between body fat percentage and the amount of information visible in images, demonstrating that increasing body fat percentage resulted in a slight decrease in observed feature counts. Subsequent analysis determined that this observed relationship between body fat percentage and feature count is not statistically significant.

Research in the field of vein visualisation has outlined the factors which have a negative impact on the ability to observe the vascular pattern clearly, with the level of subcutaneous fat being cited as a primary influencing factor. Studies undertaken to determine the effect of subcutaneous fat on the ability to visualise and access veins have stated that vein location and access in individuals with a higher body fat percentage is much more challenging than in individuals with a low percentage of body fat (Mbamalu and Banerjee, 1999; Cuper *et al*., 2013). It must be noted that the discrepancy between the findings of this study and the literature may be due to the location of the veins. For venepuncture, the preferred insertion sites (the median cubital, cephalic and basilic veins) reside in the arm (Moore *et al.*, 2011), whereas the dorsum of the hand is the region of interest with regards to this study.

The weak correlation between body fat percentage and feature count observed during this study may be explained by the small amount of fat stored within the hands. Literature has noted that the dorsum of the hand is not an important fat repository (Coleman, 2002). Alternatively, this trend may be explained by an increased visibility of veins in individuals with greater amounts of body fat when using IR imaging technologies. This theory is supported by the growing amount of IR medical imaging devices on the market to assist in viewing veins in medical settings.

12.2. Discussion of Interactions between experimental factors

Assessment was conducted to determine the influence of interacting factors on the amount of data visible in each image type. Multiple comparison analysis was undertaken to determine the interactions between experimental factors. The results of this statistical test demonstrate that the interactions between Individual and Feature Type, and Imaging Modality and Feature Type are highly significant with regards to their influence on feature count.

The interaction between Individual and Imaging Modality, and the three fold interaction between Individual, Feature Type and Imaging modality do not have a significant influence on the amount of feature count data visible in images. This is demonstrated by P values greater than the threshold of significance (0.05), with values of 0.09 and 1 respectively.

12.2.1. Interaction between Feature Type and Imaging Modality

As demonstrated in the summary report of multiple comparison analysis, the interaction between Feature Type and Imaging Modality is significant with an associated P value of less than 0.001. Graphical representation of the interaction between Imaging Modality and Feature Type follows the observed pattern of Feature Type frequency previously identified, with Lines being identified most frequently, followed by Branches, Islands, and then Intersections. Images captured using the DSLR camera consistently identified a greater number of each feature type than those acquired using the VeinViewer. This can be seen with the blue and pink data lines representing VeinViewer images being located beneath those of the DSLR images for each feature type.

The greatest number of Lines and Intersections were identified in DSLR images captured at a resolution of 9MP with the daylight off (9MPdlOFF), whilst images taken using a resolution of 0.3MP with the daylight on (0.3MPdlON) contained the greatest frequency of observable Branches and Islands. It is noted that the differences between feature counts observed in 9MPdlOFF and 0.3MPdlON images, are not considered statistically significant.

Conversely to the highest frequencies observed in the aforementioned two image types, images acquired using the VeinViewer with the daylight on consistently identified the least frequency of each feature type.

Percentage data loss calculations undertaken to determine the power of each imaging modality in discerning individual feature types, indicated that a significant proportion of feature count data was lost when images were captured using the VeinViewer. VeinViewer images consistently produced the highest figures of percentage data loss for each feature type. In the case of Islands, 57.9% of feature data was lost in images obtained using the VeinViewer with the daylight on when compared to DSLR images captured at a resolution of 0.3MP with the daylight on.

From these statistics it can be concluded that the DSLR outperforms the VeinViewer when identifying feature types.

12.2.2. Interaction between Imaging Modality and Sex

Analysis of the interaction between Imaging Modality and Sex demonstrates that there is no significant interaction between these two variables, with an associated P value of 0.983 (greater than the threshold of significance of 0.05). Whilst both Imaging Modality and Sex have a significant impact on feature count in their own right, when combined their effect is not equalised.

12.2.3. Interaction between Body Fat Percentage and Imaging Modality

Statistical analysis undertaken to determine the interaction between the factors of Body Fat Percentage and Imaging Modality has demonstrated that there is no interaction between the two factors. This is represented by the resultant P value of 1.00. This result corroborates earlier findings which highlighted a lack of significant influence of body fat percentage on feature count, as such the feature count associated with each imaging modality is also unaffected by body fat percentage.

12.2.4. Interaction between Body Fat Percentage and Feature Type

The P value of 1.00 returned from statistical analysis of the interaction between Body Fat Percentage and Feature Type indicate that any observed differences between the treatment groups cannot be considered as statistically significant. In other words, it cannot be discounted that random sampling variability is the source of any differences observed. In short, body fat percentage does not influence the type of features observed in participants.

12.3. Discussion of Study Strengths and Limitations

This study was conducted in conjunction with ongoing research in the field of Vein Pattern Analysis being undertaken by individuals at the Centre for Anatomy and Human Identification (CAHId), University of Dundee. The addition of these research findings to the body of work compiled by CAHId experts acts to progress the utility of VPA in expanding circumstances. As the application of Vein Pattern Analysis to the area of forensic human identification is considered relatively new, it is essential that research is conducted to accumulate statistical references applicable to scenarios in which this technique can be applied. These statistical references are required to produce likelihood ratios which can be presented in court to enable lay persons to comprehend the strength of the evidence.

12.3.1. Study Strengths

The database of infrared images of vein patterns created for this study acts to provide a further reference set for future VPA research. This reference set acts to bolster the data sets already compiled by CAHId. These images provide further data from which statistical figures can be calculated to determine the strength of VPA associated with images taken using the VeinViewer and DSLR camera fitted with an IR filter. With a comprehension of the integral role that reliable forensic science plays in the judicial process, it has been acknowledged that forensic analytical techniques are required to be both accurate and dependable, with statistical evidence available to corroborate the scientific basis of methods (National Research Council, 2009b; UK Government, 2013). As such, these reference sets of data provide an invaluable source for use in the courtroom to demonstrate the likelihood that suspect and offender are one and the same.

The database compiled as part of this research acts as the first established reference set of vein pattern images captured using webcam technology. The VeinViewer camera is in essence a webcam; the same hardware (minus an IR filter, to allow for images to be captured in IR), connected to a computer via a USB connection, and capturing images in real time. The methodology utilised in this study for the extraction of still images from the captured VeinViewer recordings, coupled with their subsequent analysis and recording of features, provide a procedural basis for vein pattern analysis of future cases involving webcam images. With an increase in the use of webcams for the sexual exploitation of children (Austin and Dong, 2014), such a resource is invaluable for providing a reference data set with associated statistics.

The case of R v. Mr J (discussed in Chapter 1), the need for statistics relating to the strength of analysis is apparent when the outcome of this case is considered. Whilst comparison analysis of the suspect and offender vein patterns indicated numerous points of similarity, thus prohibiting the exclusion of the suspect from investigation, the case was ultimately decided on the basis of witness testimony. The inclusion of empirical statistics relating to the strength of vein pattern evidence lend weight to analysis, thus diminishing the impact of other evidential sources which are often considered anecdotal and lacking in empirical founding (Zajac *et al*., 2013).

12.3.2. Study Limitations

With regards to the method employed for data capture, the angulation of the VeinViewer beneath the DSLR resulted in images for each device being taken from a slightly varying view. This data set up was necessary to enable images to be captured simultaneously to prevent the introduction of additional variables. Alternative camera placement such as side by side positioning would have resulted in images acquired from differing aspects, whilst the use of a swivel head for rotation of the two cameras would not have enabled simultaneous imaging. Future research may wish to address the variation in view introduced by the angulation of the VeinViewer below the DSLR.

Still images were extracted from VeinViewer recordings at the points when the hands of each subject were positioned stably in the prescribed manner. It is acknowledged that this may not have been the exact same moment at which the still images were captured using the DSLR camera. Any variation in the time between which the DSLR images were captured and the point at which stills were extracted from the VeinViewer footage would have been minimal, however it is not impossible that this difference may have introduced additional variables, for example if the participant had repositioned their hand by an increment. Future studies utilising the methodology of this study may wish to introduce a safeguard to ensure that images isolated from VeinViewer footage match exactly the time stamp at which DSLR images were captured.

Published literature addressing the factors influencing the visualisation of veins, list skin colour as an influential factor, with the veins of darker skinned individuals possessing greater amounts of melanin being less readily visible than those with fair skin (Chiao *et al.*, 2013; Mbamalu and Banerjee, 1999). Research in the fields of both medical imaging and biometric technologies have stated that infrared imaging overcomes the obstacle of skin colour when visualising veins, as the incident IR penetrates the melanin containing cell layers and is absorbed by the deoxyhaemoglobin of the veins (Soni *et al.*, 2010; Mansoor *et al.*, 2013).

To investigate the influence of skin colour on the ability of each tested IR imaging device to visualise vein patterns, participants were asked to state their ethnicity in the participant questionnaire. The majority of participants identified themselves as White, with a minority (3 individuals) identifying themselves as Asian. Within these ethnic groups, participants were provided with the opportunity to classify themselves into subdivisions. White British was the ethnic sub group to which the majority of participants classified themselves. These classification ratios reflect the demographic associated with the geographical region in which data capture was undertaken. Upon initial analysis of data, it was concluded that the classification of individuals into ethnic sub groups was not a viable method to determine skin colour of participants. Combined with the lack of ethnic variation within the sample population, it was not possible to investigate the influence of skin colour on the ability of each imaging modality to visualise vein pattern data. A more suitable method to determine skin colour may be the use of a basic skin tone chart, to which individuals could compare the colour of skin on their hand and assign themselves to a defined colour group. In addition, it may be a consideration of future research to undertake data collection in a more ethnically diverse location.

Numerous sources have cited age as an influential factor on the ability to visualize veins, with infants presenting as the most problematic subjects (Chiao *et al.*, 2013;

Fakoor *et al.*, 2013; Bravery, 2008). The strong correlation reported between increasing age and vein visibility has been attributed to the relocation of visceral adipose tissue (Chiao *et al.*, 2013), with the high body fat percentage of infants obscuring the veins. Subjects recruited for this study ranged in age from 19 to 63 years, with a median age of 33 years, and a mode of 22 years. Whilst this provides a wide spectrum of ages, insufficient numbers were available for adequate statistical analysis according to age groups. As all participants for this study were required to be aged over 18, no data was available to assess the use of the VeinViewer and DSLR in young subjects considered problematic with regards to vein visualisation. Future research may wish to recruit a large number of participants of a wider age range in order to investigate this matter.

The methodology utilised to highlight the visible vein pattern and identify vein features follows that of Meadows (2011). Whilst results showed high percentage of inter-observer agreement and reliability, it is noted that with continuous analysis of vein patterns, the observer gains greater experience and so may be more proficient in identifying vein pattern features (Meadows, 2011). In relation to this study, it is acknowledged that the large volume of images analysed by the principal investigator may have increased their ability to identify vein pattern features when compared to the first image set analysis. Such an effect may have had an influence on the results obtained. Future studies may wish to investigate the correlation between the ability of an observer to identify vein pattern features and the number of images analysed. In addition, future research may wish to assess the inter- and intra-observer repeatability and reliability of this method when analysing images capture using real time recording devices such as the VeinViewer.

13. Future Research

As the advancement of the internet has removed the physical borders which previously hindered the dissemination of material depicting the sexual exploitation of children, vein pattern analysis research must continually progress to investigate the expanding range of technologies utilised for creating such imagery.

Recent media reports have focussed upon the use of webcam technology by paedophile rings to broadcast the sexual exploitation of children live over the internet (Corcoran, 2014; Crawford, 2014; Austin and Dong, 2014). As such, it is necessary for individuals utilising VPA for the purposes of forensic human identification to be aware of the error rates and likelihood ratios associated with these imaging devices. This study has utilised infrared webcam technology in the form of the VeinViewer, and it may be of interest in future studies to undertake comparison analysis between this imaging device and a visible light counterpart. A similar methodology may be utilised, with the substitution of the DSLR camera for a standard webcam. An additional laptop would be required to facilitate the capture of two webcam videos simultaneously, with positioning of said webcams being such to ensure capture of the same field of view.

In addition to the comparison of IR and visible light webcam images, a study investigating the ability of analysts to extract vein pattern information from moving webcam recordings may be of interest. As the current study was conducted with the hand being held stationary, it may be beneficial to determine the loss of vein pattern data associated with stills taken from recordings depicting the hands in an action setting. For example, webcam recordings could be captured of participants whilst they perform a task such as a handheld puzzle, with the extracted still images being compared to those of the same individual in prescribed positions.

The data set created as a result of this current study has utility in many future areas of vein pattern analysis, such as network analysis and the dicriminating power of feature types as is currently being undertaken at CAHId.

14. Conclusion

The aim of this research was to assess the viability of the VeinViwer camera as an alternative tool to a DSLR camera for the purpose of gathering vein pattern information from a suspect whilst in the setting of a custody suite. This project has shown that the DSLR is capable of visualising a greater quantity of vein pattern information that the VeinViewer. As such, it can be concluded that the VeinViwer is not a viable alternative to the DSLR in gatering vein pattern evidence.

14.1. Performance

The results of statistical analysis conducted on the data set created by this research has concluded that the DSLR camera consitently visualised a significantly greater amount of vein pattern information than the VeinViewer. The DSLR camera was found to reliably identify vein pattern data at both resolutions utilised (0.3MP and 9MP), with no significant difference found between feature counts obatined from each image type. Whilst it is beneficial to conduct similar analysis of images obtained from perpetrator images and those captured in custody (i.e. comparison of images at the same resolution and IR wavelength), the more information obtainable for comparison analysis clearly contributes to the corroborating evidence of a case. It is however acknowledged that more detail will be visible in suspect images obtained in the custody suite under controlled conditions than in offender images.

On the basis of visible vein information, the imaging modality recommended for use in obtaining suspect images in the custody suite is the DSLR.

In terms of use in custody suites of various luminance, this study has found that images acquired by the DSLR at 9MP are most consistent. Images obatined by the DSLR and VeinViewer at 0.3MP were found to be influenced by lighting conditions.

As it would be desirable for equpiment to perform reliably in a variety of settings, the DSLR camera at 9MP is recommended for use as no significant difference was found between the amount of feature count data observed in images acquired with the daylight in the ON and OFF settings.

When assessing the ability of the imaging modalities being tested to observe distinct feature types, it is noted that again the DSLR at both settings outperformed the VeinViewer. The difference between DSLR images obtained at both test resolutions found no significant difference. Percentage data loss calculations found that the loss of feature data associated with images obatined using the VeinViewer ranged from 15.9% to 57.9%. In comparison, the greatest percentage data loss observed in DSLR images was found to be 19.7%. As a result of statistical analysis undertaken, it can be concluded that the DSLR is more reliable than the VeinViewer in identifying vein patterns.

This study found no significant correlation between sex, body fat percentage and imaging modality, with the DSLR maintaining superior performance.

14.2. Cost

In terms of equipment cost, the VeinViewer device utilised for this study is readily avaiable on the open market from £56.99. More complex medical grade IR vein visualistaion systems are avaiable, however the cost of even basic models commences at five times the amount of the USB device utilised here.

It must be noted that in the case of the basic model utilised for this study, a laptop is required to both capture and process the images acquired by this device. The expense of a laptop with a processing system sufficint to capture and store these images must also be taken into account. For advanced IR vein visualisation systems which enable still images of vein patterns to be acquired, independent processing systems and monitors are often required.These are often provided with the imaging devices at a cost of many thousands of pounds.

With regards to training costs, the low grade VeinViewer utilised for this research is marketed as an educational tool; as such, it has been designed for ease of use, requiring little training prior to effective use, thus minimising training costs.

DSLR cameras are considered a standard element of evidence collecting kits worldwide. Most modern DSLR cameras are equipped with high powered charged coupling devices (CCDs) capable of capturing a great range of light wavelengths including IR. If the model of camera utilised by a police force does not have the capacity to obtain IR images, DSLR cameras engineered specifically to capture IR images are avaible from £280. Whilst this cost exceeds that of the VeinViewer device utilised by this study, no external laptop is required to capture images as they are stored on an internal memory card.

As evidence collection officers are familiar with the basics of DSLR camera function, little training is required to familiarise individuals with IR settings.

To summarise, with regards to cost benefit analysis, the DSLR camera is to be recommended for use in obtaining IR suspect images in the custody suite for use in vein pattern analysis.

14.3 Rejection of Hypothesis

It was hypothsised that the VeinViewer camer could be utilised as a low cost alternative to the current DSLR camera employed in collecting vein pattern evidence in the setting of the custody suite. This hypothesis was generated as the VeinViewer is marketed as a IR vein visualisation tool, and so it was proposed that this device would outperform the DSLR camera which is designed primarily to capture still images in visible light. The hypothesis stated that the VeinViewer would be capable of visualising larger quantities of vein pattern information in all participants than the DSLR. This study has shown that in contrast to this assumption, the VeinViewer consistently identified less vein pattern information than the DSLR camera, leading to the rejection of this hypothesis.

15. Closing Statement

Photography has long proven a useful evidentiary tool in the forensic arena. As photographic technology advances, practitioners of forensic science must ensure that they understand the functionality of methods so as to maximise their utility in the investigation of crime. Images connected with the sexual exploitation of children have advanced from glass plate photography to modern digital files with the advancement of imaging technology. It is the duty of investigators to research these technologies in order to understand their utility and in turn to analyse resultant images to garner all available information which may be of use in investigations.

It is for this reason that research such as this study is undertaken, to provide reliable and accurate means of analysing photographic evidence.

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Appendix A

Invitation to participate distributed via the University of Dundee's weekly e-mail distribution programme.

Submitted for consideration on 05/04/2013

Published in newsletter 03/05/2013

WOULD YOU LIKE TO PARTICIPATE IN CUTTING EDGE FORENSIC RESEARCH?

We are looking for volunteers to participate in Vein Pattern Analysis Research. Participation involves having a series of photographs and a video taken of your hands using an Infra-Red camera and will take no more than 10minutes. Males/females of all ages required.

For further info contact rsaiken@dundee.ac.uk

Appendix B

Call for participants submitted to the University of Dundee's School of Medicine weekly.

Submitted 21/04/13

WOULD YOU LIKE TO PARTICIPATE IN CUTTING EDGE FORENSIC RESEARCH?

Do you have a spare 10 minutes?

We are looking for volunteers to participate in Vein Pattern Analysis Research. Participation requires infrared digital images to be taken of hands to analyse vein patterns.

You may be aware of this field of research and may have even participated in our sister study; we are now collecting images using different imaging devices and so would be grateful for your help.

Data collection will take place in Ninewells Library, Teaching Room 7, from 9am to 5pm, May 1st – 3rd.

Data collection will take no more than 10minutes.

For further info contact rsaiken@dundee.ac.uk

Appendix C

Call for participants distributed via the internal email system of the College of Life Sciences.

Distributed 03/05/2013

WOULD YOU LIKE TO PARTICIPATE IN CUTTING EDGE FORENSIC RESEARCH?

Do you have a spare 15 minutes?

We are looking for volunteers to participate in Vein Pattern Analysis Research. Participation requires infrared digital images to be taken of hands to analyse vein patterns.

You may be aware of this field of research and may have even participated in our sister study; we are now collecting images using different imaging devices and so would be grateful for your help.

Data collection will take place in MSI Anatomy Museum, Monday 6th of May (9am to 5pm) and Tuesday 7th May (9am to 1pm).

Data collection will take no more than 15minutes.

For further info contact rsaiken@dundee.ac.uk

Appendix D

Participant information sheet.

PARTICIPANT INFORMATION SHEET

Title of project: A comparison of two different vein imaging modalities. Assessing how image quality impacts upon the accuracy of vein pattern analysis.
Principle investigator: Rachel Aiken, Centre for Anatomy and Human Identification
Supervisors: Prof. Sue Black & Dr. Helen Meadows, Centre for Anatomy and Human Identification

You have been invited to participate in a research study being conducted in the Centre for Anatomy and Human identification (CAHID) at the University of Dundee. Your participation is voluntary and you may withdraw consent at any time, without explanation.
Please take you time to read the following information and consider your decision. If you have any further questions, please do not hesitate to contact the principal investigator.

Project Summary
The patterns created by the superficial network of veins on the back of the hand have been found to have discriminatory properties. These properties have been exploited by the biometrics industry by using vein patterns as an authenticator to aid identification or exclusion of an individual.

This approach of using vein patterns as an aid to identification or exclusion of an individual was introduced to the field of forensic science in 2007 by Professor Black and the National Police Improvements Agency (NPIA), with this method now being considered admissible in U.K courts.

The aim of this project is to determine the most effective imaging modality for viewing the superficial veins of the hand to provide recommendation for the use of the more accurate device.

Role of Participant
As a participant you will be requested to have a series of images taken of the back of your hand to expand the database of hand images already held in CAHID. Images will be taken in Infra-Red (IR) light using two imaging modalities, in the following specified hand positions:

Images taken using a high quality camera fitter with an IR filter:
- Back of hand (fingers extended)
- Back of hand (fist clenched)
- Back of hand (alternative pose)

Whilst these images are being taken a real-time video will be recorded using a vein viewer camera. This camera uses infra-red light to visualise the veins underneath the skin.

Finally you will be asked to have your body fat percentage measured. This will involve having your height measured before standing on a specially adapted set of weighing scales.
It is advised in the manufacturer's guidelines that these weighing scales should not be used if you have a heart pace maker fitted.
If you have a pacemaker fitted, you will be offered an alternative method of recording body fat percentage. This will comprise of skin fold thickness measurements.

All images and measurements will be taken in one session and will take a maximum of 15 minutes.

Your participation is voluntary and you may decide to stop being part of the research study at any time without explanation. You are entitled to take part in all, some or no aspects of the study. Should you wish to omit consent of any part of the data collection, please specify on the supplied consent form.

Exclusion criteria
- Participants must be aged over 18 years

The only perceivable risk in this study is to those fitted with a heart pace maker. The manufacturers of the weighing scales used in this study advise that those fitted with a pacemaker should not use the scales. If you have a pacemaker fitted, you will have to be excluded from this section of the study and you will be offered an alternative method of recording body fat percentage (skin fold thickness measurement).
Pregnant women will also be excluded from this aspect of the study, but will also be offered the alternative method.

Confidentiality/Anonymity
The images obtained in this study will only be identifiable to the principle investigator and their supervisors. The data will be stored securely on a password access controlled database and will comply with the Data Protection Act 1998.
Findings from the research may be published in relevant journals and presented at conferences attended by the principal investigator and/or the student's supervisor; however no identifiable information will be included in such publications.

For further information about this research please contact:

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The University Research Ethics Committee of the University of Dundee has reviewed and approved this research study.

Appendix E

Personal information and basic health questionnaire.

PARTICIPANT QUESTIONNAIRE

Thank you for taking part in this study. The following questions are designed to help the principal investigator and your answers will be appreciated. However, please omit any questions you do not wish to answer.

Your responses will be treated as strictly confidential and will be used only for the purposes stated in the information sheet and in compliance with The University of Dundee Code of Practice for Research Ethics on Human Participants.

Personal Information

Male ☐ Trans-sexual (Female to Male) ☐

Female ☐ Trans-sexual (Male to Female) ☐

Age: ☐☐

Dominant hand: Left ☐ Ambidextrous ☐

Right ☐

Ethnicity:

White; British ☐ Irish ☐ European ☐

Other. Please specify ______________________

Black; Caribbean ☐ African ☐

Other. Please specify ______________________

Asian; Indian ☐ Pakistani ☐ Bangladeshi ☐

Chinese ☐ Other. Please specify ______________________

Mixed; White & Black Caribbean ☐ White & Black African ☐

White & Asian ☐ Other. Please specify ______________________

Body Fat Percentage Measurements

Due to the manufacturer recommendations if you have a heart pacemaker fitted, you will not be able to have your body fat percentage measured using the specially adapted weighing scales and will be excluded from this section of the study.

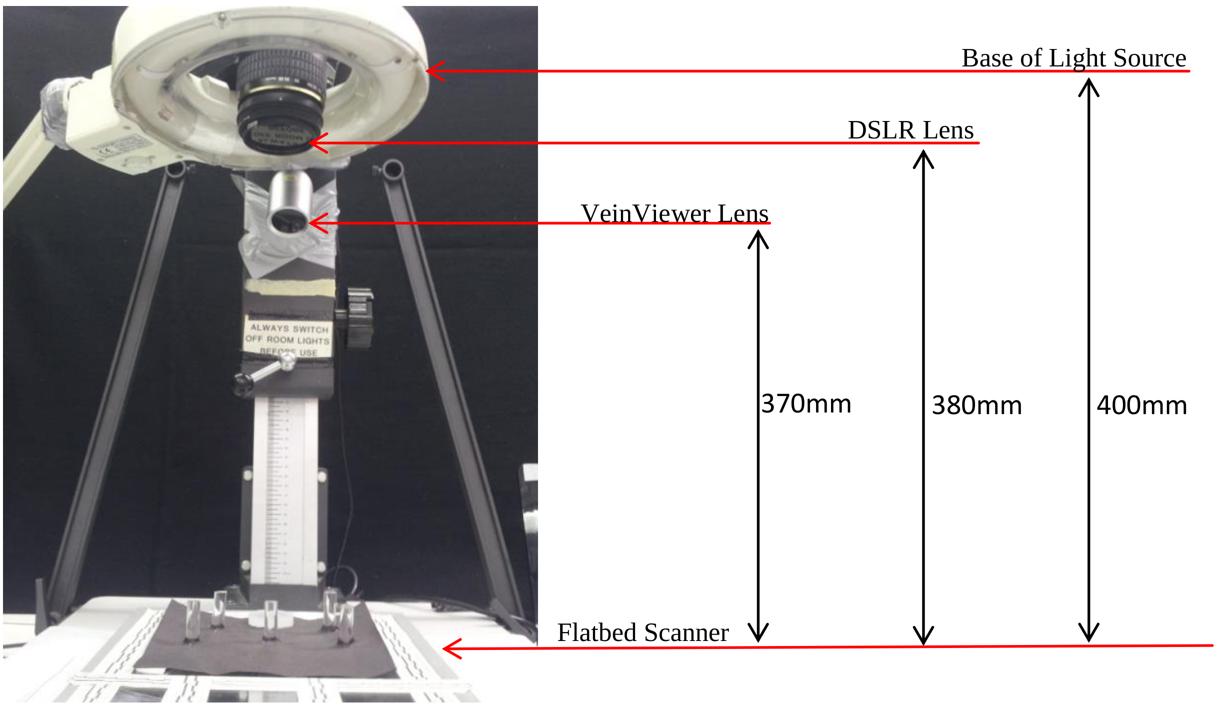
	Y	**N**
Do you have a heart pace maker fitted?	☐	☐
Are you pregnant?	☐	☐

Appendix F

Set up procedure.

1. Assemble height scale
2. Sanitise and set up BIA scales
3. Attach camera to photographic rig
4. Attach IR lens (780nm) to camera via step down ring
5. Set camera to Programmed Auto mode (P)
6. Adjust camera settings using FinePix Photo Mode;
   - Quality: 9MP or 0.3MP
   - Sensitivity: ISO 80
   - Colour: Black and White
7. Secure VeinViewer to camera rig at base of camera fixation point, ensuring an angle of 116^{0}
8. Attach VeinViewer to laptop and set destination file
9. Position light source and secure
10. Position flatbed scanner within demarcation lines on base of rig
11. Check positioning of elements as detailed in Diagram 1.
12. Test all equipment to ensure correct functioning and positioning

Diagram 1; Positioning of equipment.



Appendix G

Feature Count Data for each individual.

Participant	Feature	Feature Total per Image Type					
		9MPdION	9MPdIOFF	3MPdION	3MPdIOFF	VVdION	VVdIOFF
P002L	Line	24	36	30	19	19	24
	Branch	14	24	24	10	10	14
	Island	3	8	9	2	2	3
	Intersection	0	1	0	0	0	0
		41	69	63	31	31	41
P002R	Line	13	8	9	10	14	9
	Branch	6	3	2	5	5	6
	Island	1	1	1	2	2	2
	Intersection	1	1	2	2	1	1
		21	13	14	19	22	18
P003L	Line	11	20	18	7	12	10
	Branch	5	10	9	2	6	5
	Island	1	1	1	0	0	0
	Intersection	1	1	1	1	0	0
		18	32	29	10	18	15
P003R	Line	16	8	9	11	11	7
	Branch	8	3	4	6	5	3
	Island	1	1	1	1	0	0
	Intersection	1	0	1	0	0	0
		26	12	15	18	16	10
P004L	Line	18	28	13	15	16	14
	Branch	9	14	7	7	9	8
	Island	2	3	1	1	1	1
	Intersection	0	1	0	0	0	0
		29	46	21	23	26	23
P004R	Line	26	17	26	28	10	18
	Branch	17	9	17	18	5	8
	Island	6	2	7	7	1	4
	Intersection	2	0	2	3	0	3
		51	28	52	56	16	33
P005L	Line	6	8	6	7	10	12
	Branch	1	2	1	3	4	4
	Island	0	0	0	1	0	0
	Intersection	0	0	0	0	0	0
		7	10	7	11	14	16
P005R	Line	10	15	7	15	11	9
	Branch	8	9	10	9	5	4
	Island	3	3	3	3	1	0
	Intersection	0	0	0	0	0	0
		21	27	20	27	17	13
P006L	Line	27	20	26	23	20	18
	Branch	13	10	19	14	10	13
	Island	4	1	4	3	2	4
	Intersection	1	0	1	0	0	0

		45	31	50	40	32	35
P006R	Line	18	18	20	21	14	14
	Branch	9	8	11	10	7	7
	Island	4	2	2	2	1	1
	Intersection	3	0	0	0	0	0
		34	28	33	33	22	22
P007L	Line	14	15	10	8	9	11
	Branch	6	8	5	1	4	4
	Island	2	2	1	0	1	1
	Intersection	1	1	1	1	1	1
		23	26	17	10	15	17
P007R	Line	10	10	14	16	10	10
	Branch	5	4	6	7	6	5
	Island	2	1	2	2	1	2
	Intersection	1	1	2	2	0	1
		18	16	24	27	17	18
P008L	Line	12	16	18	12	9	16
	Branch	6	9	10	5	4	9
	Island	1	2	2	0	0	2
	Intersection	0	2	0	0	0	0
		19	29	30	17	13	27
P008R	Line	13	12	12	8	10	12
	Branch	6	5	7	4	4	5
	Island	0	0	1	1	0	0
	Intersection	0	0	0	0	0	0
		19	17	20	13	14	17
P009L	Line	15	22	10	14	13	12
	Branch	8	14	8	9	12	8
	Island	4	5	3	2	5	4
	Intersection	0	0	0	0	0	1
		27	41	21	25	30	25
P009R	Line	23	19	16	20	12	14
	Branch	16	11	10	12	6	6
	Island	6	3	3	4	2	2
	Intersection	1	0	0	0	1	2
		46	33	29	36	21	24
P010L	Line	16	31	23	13	13	16
	Branch	9	18	18	7	10	9
	Island	4	6	8	1	3	3
	Intersection	1	1	2	0	0	1
		30	56	51	21	26	29
P010R	Line	17	20	19	16	13	12
	Branch	13	12	12	11	9	7
	Island	3	4	5	4	2	3
	Intersection	0	2	2	0	0	2
		33	38	38	31	24	24
P011L	Line	16	25	14	16	10	16
	Branch	4	14	9	9	6	7
	Island	0	5	3	1	2	2
	Intersection	1	1	1	0	1	1
		21	45	27	26	19	26

P011R	Line	10	8	10	11	10	8
	Branch	5	3	4	4	5	4
	Island	1	0	1	0	1	1
	Intersection	0	0	1	0	0	0
		16	11	16	15	16	13
P012L	Line	20	26	17	17	13	15
	Branch	11	16	9	10	7	8
	Island	2	4	1	2	1	1
	Intersection	0	1	0	0	0	0
		33	47	27	29	21	24
P012R	Line	12	10	12	10	10	8
	Branch	4	7	5	3	4	3
	Island	0	0	1	0	0	0
	Intersection	1	1	1	1	0	0
		17	18	19	14	14	11
P013L	Line	6	12	6	4	6	6
	Branch	1	4	2	1	2	2
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		7	16	8	5	8	8
P013R	Line	6	12	8	3	10	10
	Branch	1	4	3	1	3	4
	Island	0	1	1	0	0	1
	Intersection	0	0	0	0	0	0
		7	17	12	4	13	15
P014L	Line	13	24	12	16	8	6
	Branch	6	15	10	10	3	2
	Island	2	7	3	3	0	0
	Intersection	0	3	0	0	0	0
		21	49	25	29	11	8
P014R	Line	13	12	18	13	9	9
	Branch	5	5	8	6	4	3
	Island	2	3	2	2	0	0
	Intersection	2	2	2	2	0	0
		22	22	30	23	13	12
P015L	Line	14	21	14	10	12	15
	Branch	7	13	8	4	5	6
	Island	1	4	2	0	0	0
	Intersection	0	1	0	0	0	1
		22	39	24	14	17	22
P015R	Line	16	14	18	14	16	16
	Branch	6	6	7	5	6	6
	Island	1	2	1	1	1	1
	Intersection	1	1	1	1	0	0
		24	23	27	21	23	23
P016L	Line	11	22	14	21	16	17
	Branch	4	15	6	12	8	7
	Island	1	5	1	3	3	1
	Intersection	2	3	2	2	2	2
		18	45	23	38	29	27
P016R	Line	13	15	17	11	11	13

	Branch	8	8	10	5	5	6
	Island	1	1	2	1	0	1
	Intersection	1	0	0	0	0	1
		23	24	29	17	16	21
P017L	Line	4	8	8	6	6	6
	Branch	1	2	3	2	1	2
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		5	10	11	8	7	8
P017R	Line	2	2	2	2	2	2
	Branch	0	0	0	0	0	0
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		2	2	2	2	2	2
P018L	Line	4	12	6	6	6	11
	Branch	1	6	1	2	2	5
	Island	0	1	0	0	0	1
	Intersection	0	0	1	0	0	1
		5	19	8	8	8	18
P018R	Line	4	4	8	4	7	7
	Branch	1	1	3	1	3	3
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		5	5	11	5	10	10
P019L	Line	4	9	6	4	6	9
	Branch	1	2	1	1	1	4
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		5	11	7	5	7	13
P019R	Line	6	4	8	4	6	8
	Branch	2	0	1	1	0	1
	Island	0	0	0	0	0	1
	Intersection	0	0	0	0	0	0
		8	4	9	5	6	10
P020L	Line	15	26	14	14	12	16
	Branch	5	15	7	8	8	10
	Island	4	12	5	6	4	4
	Intersection	2	7	4	5	2	1
		26	60	30	33	26	31
P020R	Line	19	19	14	13	18	14
	Branch	10	11	7	9	7	10
	Island	3	3	2	3	0	4
	Intersection	2	0	0	0	0	1
		34	33	23	25	25	29
P023L	Line	16	14	16	7	13	11
	Branch	6	5	7	3	3	3
	Island	1	0	2	1	1	0
	Intersection	2	1	2	1	2	1
		25	20	27	12	19	15
P023R	Line	18	16	18	21	20	24
	Branch	10	7	14	11	9	15

	Island	2	2	5	3	0	3
	Intersection	1	0	0	2	0	0
		31	25	37	37	29	42
P026L	Line	12	12	16	8	14	8
	Branch	2	3	6	2	4	2
	Island	0	1	0	0	0	0
	Intersection	2	2	1	1	2	1
		16	18	23	11	20	11
P026R	Line	10	12	14	12	8	14
	Branch	3	5	5	5	2	7
	Island	0	0	1	1	0	0
	Intersection	1	0	2	1	1	0
		14	17	22	19	11	21
P027L	Line	17	12	9	9	14	13
	Branch	8	3	2	3	5	6
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		25	15	11	12	19	19
P027R	Line	17	10	20	14	10	14
	Branch	9	5	12	6	7	9
	Island	2	1	4	1	2	1
	Intersection	0	0	1	1	0	0
		28	16	37	22	19	24
P029L	Line	22	18	19	14	22	20
	Branch	16	11	13	7	13	12
	Island	7	5	5	3	5	5
	Intersection	3	2	1	3	0	2
		48	36	38	27	40	39
P029R	Line	15	17	25	23	17	19
	Branch	10	10	17	15	11	12
	Island	3	3	5	3	4	3
	Intersection	1	1	1	0	1	0
		29	31	48	41	33	34
P030L	Line	8	8	8	8	8	8
	Branch	2	2	2	2	1	2
	Island	0	0	0	0	0	0
	Intersection	1	1	1	1	2	1
		11	11	11	11	11	11
P030R	Line	10	12	17	13	8	8
	Branch	5	6	8	7	4	4
	Island	1	1	2	2	1	1
	Intersection	0	0	1	1	0	0
		16	19	28	23	13	13
P031L	Line	13	14	15	15	11	7
	Branch	7	8	7	7	5	2
	Island	0	1	0	0	0	1
	Intersection	0	0	0	0	0	1
		20	23	22	22	16	11
P031R	Line	15	15	16	15	7	11
	Branch	9	9	12	8	4	5
	Island	2	2	4	3	0	0

	Intersection	0	0	0	1	0	0
		26	26	32	27	11	16
P038L	Line	12	8	11	10	14	15
	Branch	6	4	6	5	7	10
	Island	1	1	1	1	1	4
	Intersection	0	0	0	0	0	1
		19	13	18	16	22	30
P038R	Line	12	12	14	2	5	13
	Branch	4	3	8	0	1	6
	Island	0	1	1	0	0	2
	Intersection	2	1	0	0	0	3
		18	17	23	2	6	24
P039L	Line	11	13	16	13	13	14
	Branch	7	7	10	8	6	9
	Island	2	2	2	2	0	2
	Intersection	0	0	0	0	0	0
		20	22	28	23	19	25
P039R	Line	14	16	23	9	12	17
	Branch	5	7	18	4	5	13
	Island	0	1	7	0	0	5
	Intersection	0	0	1	0	0	0
		19	24	49	13	17	35
P040L	Line	18	16	21	12	12	13
	Branch	9	7	12	5	5	7
	Island	0	2	2	0	0	1
	Intersection	0	1	0	0	0	0
		27	26	35	17	17	21
P040R	Line	14	13	16	13	9	18
	Branch	6	7	11	8	3	11
	Island	1	1	3	2	0	4
	Intersection	2	0	0	0	0	1
		23	21	30	23	12	34
P041L	Line	6	14	4	4	5	6
	Branch	2	7	1	1	2	2
	Island	0	1	0	0	0	0
	Intersection	0	0	0	0	0	0
		8	22	5	5	7	8
P041R	Line	4	4	4	4	6	8
	Branch	1	1	1	1	2	3
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		5	5	5	5	8	11
P042L	Line	9	8	14	12	9	9
	Branch	6	3	11	7	4	3
	Island	2	2	4	1	0	1
	Intersection	1	2	1	0	0	0
		18	15	30	20	13	13
P042R	Line	10	10	14	9	7	7
	Branch	3	4	8	4	3	3
	Island	0	0	1	0	0	0
	Intersection	0	0	0	0	0	0

		13	14	23	13	10	10
P043L	Line	15	24	17	15	16	14
	Branch	9	11	10	5	8	7
	Island	2	3	3	0	1	1
	Intersection	0	2	0	0	0	0
		26	40	30	20	25	22
P043R	Line	14	13	15	17	9	12
	Branch	9	7	11	12	7	6
	Island	2	1	3	4	3	1
	Intersection	0	0	0	1	1	0
		25	21	29	34	20	19
P044L	Line	2	4	2	2	2	2
	Branch	0	0	0	0	0	0
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		2	4	2	2	2	2
P044R	Line	3	4	12	6	4	4
	Branch	1	1	8	0	0	0
	Island	0	0	3	0	0	0
	Intersection	0	0	0	1	0	0
		4	5	23	7	4	4
P046L	Line	20	17	17	14	16	14
	Branch	14	11	13	10	8	6
	Island	5	6	4	4	2	1
	Intersection	0	1	0	0	1	1
		39	35	34	28	27	22
P046R	Line	12	8	13	12	13	13
	Branch	8	3	10	9	6	6
	Island	2	0	4	3	0	0
	Intersection	0	0	0	0	0	0
		22	11	27	24	19	19
P047L	Line	17	17	15	18	17	17
	Branch	10	10	9	9	10	9
	Island	2	3	2	1	1	2
	Intersection	0	0	0	0	0	1
		29	30	26	28	28	29
P047R	Line	8	8	8	8	4	12
	Branch	1	3	2	3	2	4
	Island	0	0	0	0	1	0
	Intersection	1	0	1	0	0	1
		10	11	11	11	7	17
P048L	Line	24	18	16	10	9	10
	Branch	16	10	11	12	4	4
	Island	5	1	3	2	0	0
	Intersection	0	0	0	1	0	0
		45	29	30	25	13	14
P048R	Line	13	14	15	15	9	15
	Branch	8	5	6	8	4	10
	Island	2	2	2	2	1	2
	Intersection	0	2	3	0	0	0
		23	23	26	25	14	27

P049L	Line	11	12	11	7	10	10
	Branch	7	7	7	3	8	4
	Island	2	3	2	1	3	1
	Intersection	0	1	0	1	0	1
		20	23	20	12	21	16
P049R	Line	15	15	7	7	13	17
	Branch	9	6	2	2	5	7
	Island	3	0	0	0	1	1
	Intersection	1	1	1	1	2	1
		28	22	10	10	21	26
P050L	Line	9	7	8	7	7	9
	Branch	2	3	4	2	1	4
	Island	0	0	0	0	0	0
	Intersection	0	1	0	0	0	0
		11	11	12	9	8	13
P050R	Line	13	10	14	13	9	12
	Branch	7	4	7	7	4	5
	Island	2	2	1	3	2	3
	Intersection	1	2	1	2	2	2
		23	18	23	25	17	22
P051L	Line	17	17	12	12	13	15
	Branch	13	12	8	7	8	10
	Island	4	4	2	2	3	3
	Intersection	1	0	0	1	1	1
		35	33	22	22	25	29
P051R	Line	7	10	9	7	4	8
	Branch	3	3	4	3	3	3
	Island	0	0	0	0	1	0
	Intersection	0	0	0	0	0	0
		10	13	13	10	8	11
P052L	Line	9	10	11	7	12	10
	Branch	5	6	5	3	4	3
	Island	1	2	0	0	0	0
	Intersection	0	0	0	0	0	0
		15	18	16	10	16	13
P052R	Line	5	6	6	5	6	9
	Branch	2	1	2	2	1	3
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		7	7	8	7	7	12
P053L	Line	17	17	13	14	14	12
	Branch	7	7	6	6	6	5
	Island	1	1	2	1	0	1
	Intersection	1	2	2	1	1	1
		26	27	23	22	21	19
P053R	Line	14	14	12	12	14	20
	Branch	6	6	7	6	6	11
	Island	1	1	3	2	0	3
	Intersection	0	0	0	0	0	0
		21	21	22	20	20	34
P054L	Line	18	25	16	19	16	18

	Branch	8	13	7	9	8	8
	Island	0	5	0	1	1	0
	Intersection	0	3	0	1	0	0
		26	46	23	30	25	26
P054R	Line	12	14	12	12	11	20
	Branch	8	7	8	6	4	12
	Island	2	2	2	1	0	4
	Intersection	0	0	0	0	0	1
		22	23	22	19	15	37
P055L	Line	10	13	17	12	13	13
	Branch	5	5	12	6	5	6
	Island	1	1	3	2	0	1
	Intersection	0	1	0	0	0	0
		16	20	32	20	18	20
P055R	Line	21	14	18	12	12	18
	Branch	13	7	9	6	5	9
	Island	4	2	4	2	1	3
	Intersection	0	1	3	0	1	1
		38	24	34	20	19	31
P056L	Line	15	13	15	18	15	15
	Branch	9	8	10	8	8	9
	Island	3	4	4	1	4	4
	Intersection	1	2	1	0	2	2
		28	27	30	27	29	30
P056R	Line	22	16	14	16	16	11
	Branch	17	10	10	11	8	8
	Island	6	3	4	3	2	2
	Intersection	0	0	0	0	0	0
		45	29	28	30	26	21
P057L	Line	13	14	6	4	8	8
	Branch	5	6	2	1	2	3
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		18	20	8	5	10	11
P057R	Line	16	7	7	10	6	6
	Branch	8	4	4	4	2	2
	Island	1	0	1	0	0	0
	Intersection	0	0	0	0	0	0
		25	11	12	14	8	8
P058L	Line	14	15	14	16	8	13
	Branch	6	7	6	7	4	6
	Island	1	1	1	1	0	0
	Intersection	0	0	0	1	0	0
		21	23	21	25	12	19
P058R	Line	24	24	21	24	21	11
	Branch	11	7	11	14	8	2
	Island	0	0	1	5	0	0
	Intersection	1	1	0	2	1	0
		36	32	33	45	30	13
P059L	Line	9	10	16	12	26	20
	Branch	6	4	9	8	11	10

	Island	1	1	1	2	0	2
	Intersection	0	0	0	0	0	0
		16	15	26	22	37	32
P059R	Line	12	6	6	10	14	10
	Branch	4	1	1	3	3	3
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	1	0
		16	7	7	13	18	13
P060L	Line	8	8	3	6	12	5
	Branch	6	3	2	2	4	2
	Island	1	0	1	0	0	0
	Intersection	0	0	0	0	0	0
		15	11	6	8	16	7
P060R	Line	11	10	6	12	6	5
	Branch	5	4	2	5	2	2
	Island	1	1	0	1	0	0
	Intersection	1	1	0	1	0	0
		18	16	8	19	8	7
P061L	Line	16	24	21	16	13	12
	Branch	11	15	15	6	7	7
	Island	4	6	5	3	1	2
	Intersection	1	1	0	4	0	0
		32	46	41	29	21	21
P061R	Line	23	24	20	18	16	10
	Branch	17	12	14	16	7	5
	Island	6	4	7	6	0	0
	Intersection	1	3	3	1	0	0
		47	43	44	41	23	15
P062L	Line	14	14	13	10	15	13
	Branch	9	8	9	7	10	6
	Island	3	3	3	3	3	0
	Intersection	0	0	0	1	0	0
		26	25	25	21	28	19
P062R	Line	10	12	6	8	6	6
	Branch	3	5	3	3	1	2
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	1	0
		13	17	9	11	8	8
P063L	Line	18	23	23	15	20	25
	Branch	13	16	14	11	13	16
	Island	6	5	5	4	4	4
	Intersection	1	0	0	0	0	0
		38	44	42	30	37	45
P063R	Line	18	10	16	20	16	13
	Branch	12	5	10	11	6	10
	Island	3	2	3	4	2	3
	Intersection	0	1	0	1	2	0
		33	18	29	36	26	26
P064L	Line	16	26	17	15	15	15
	Branch	13	15	12	9	7	6
	Island	5	4	4	4	1	1

	Intersection	0	1	0	1	0	1
		34	46	33	29	23	23
P064R	Line	19	18	20	16	17	14
	Branch	8	8	9	5	5	7
	Island	1	2	1	1	0	1
	Intersection	1	1	0	2	2	2
		29	29	30	24	24	24
P065L	Line	16	15	22	13	15	14
	Branch	8	6	11	7	8	6
	Island	2	3	1	1	2	1
	Intersection	1	2	0	0	1	1
		27	26	34	21	26	22
P065R	Line	17	14	13	14	12	12
	Branch	8	6	6	7	3	5
	Island	1	1	1	1	0	1
	Intersection	1	1	0	0	0	0
		27	22	20	22	15	18
P066L	Line	20	13	24	17	20	21
	Branch	14	7	15	10	14	14
	Island	5	2	5	1	3	3
	Intersection	0	1	1	0	0	0
		39	23	45	28	37	38
P066R	Line	23	23	20	23	22	17
	Branch	14	15	11	18	14	11
	Island	5	4	2	7	3	4
	Intersection	1	0	0	0	0	0
		43	42	33	48	39	32
P067L	Line	18	21	19	20	18	15
	Branch	10	13	9	11	8	8
	Island	2	3	2	2	1	1
	Intersection	0	0	2	0	0	0
		30	37	32	33	27	24
P067R	Line	21	18	21	14	11	11
	Branch	12	9	10	8	7	8
	Island	4	3	3	2	2	2
	Intersection	2	1	2	1	1	0
		39	31	36	25	21	21
P068L	Line	15	15	15	19	12	11
	Branch	5	7	7	11	4	6
	Island	1	1	1	3	1	1
	Intersection	1	1	1	1	1	0
		22	24	24	34	18	18
P068R	Line	22	20	22	18	11	14
	Branch	12	11	12	12	5	5
	Island	4	4	4	4	2	1
	Intersection	2	2	2	2	2	2
		40	37	40	36	20	22
P069L	Line	19	22	22	21	18	15
	Branch	12	9	15	12	9	7
	Island	3	3	5	4	1	1
	Intersection	1	2	2	1	1	1

		35	36	44	38	29	24
P069R	Line	16	16	18	16	14	10
	Branch	8	9	9	10	6	6
	Island	3	3	3	3	1	1
	Intersection	1	0	1	0	0	0
		28	28	31	29	21	17
P071L	Line	15	16	16	10	8	9
	Branch	10	10	11	7	2	3
	Island	3	4	4	3	0	0
	Intersection	0	1	0	1	0	0
		28	31	31	21	10	12
P071R	Line	22	16	16	16	4	6
	Branch	12	8	9	9	1	2
	Island	4	3	3	5	0	0
	Intersection	1	2	2	2	0	0
		39	29	30	32	5	8
P072L	Line	8	9	7	8	6	8
	Branch	0	1	1	0	6	3
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	1	1
		8	10	8	8	13	12
P072R	Line	4	4	4	4	2	2
	Branch	1	1	1	1	0	0
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		5	5	5	5	2	2
P073L	Line	14	14	14	13	9	10
	Branch	6	6	7	5	3	4
	Island	1	1	1	1	1	0
	Intersection	1	1	0	2	0	1
		22	22	22	21	13	15
P073R	Line	14	12	9	13	12	11
	Branch	6	4	4	7	3	4
	Island	1	0	0	1	0	0
	Intersection	0	0	0	0	0	1
		21	16	13	21	15	16
P074L	Line	14	18	11	11	13	16
	Branch	7	9	7	6	7	7
	Island	1	1	2	1	2	0
	Intersection	0	0	0	0	1	0
		22	28	20	18	23	23
P074R	Line	14	15	11	15	10	9
	Branch	5	7	4	7	3	3
	Island	2	3	2	3	1	1
	Intersection	3	3	3	3	2	2
		24	28	20	28	16	15
P075L	Line	16	10	11	13	12	16
	Branch	8	5	6	7	3	7
	Island	2	2	1	2	0	0
	Intersection	1	1	0	1	0	0
		27	18	18	23	15	23

P075R	Line	13	14	15	11	10	12
	Branch	9	8	10	7	5	7
	Island	3	2	3	2	1	2
	Intersection	0	0	0	0	0	0
		25	24	28	20	16	21
P076L	Line	4	6	6	4	6	4
	Branch	0	1	2	0	2	1
	Island	0	0	1	0	0	0
	Intersection	1	1	1	1	0	0
		5	8	10	5	8	5
P076R	Line	4	3	4	6	4	4
	Branch	1	1	1	2	0	3
	Island	0	0	0	0	0	1
	Intersection	0	0	0	0	0	0
		5	4	5	8	4	8
P077L	Line	18	15	15	16	10	10
	Branch	10	8	5	7	4	3
	Island	2	2	1	1	0	0
	Intersection	0	2	2	1	1	1
		30	27	23	25	15	14
P077R	Line	21	14	18	17	15	16
	Branch	9	4	9	8	6	7
	Island	1	0	2	1	0	2
	Intersection	1	1	1	1	1	2
		32	19	30	27	22	27
P078L	Line	6	6	10	4	4	4
	Branch	2	1	3	1	1	1
	Island	0	0	0	0	0	0
	Intersection	0	1	1	0	0	0
		8	8	14	5	5	5
P078R	Line	16	14	14	16	9	14
	Branch	8	6	8	9	3	9
	Island	1	0	2	1	0	2
	Intersection	0	0	0	0	0	0
		25	20	24	26	12	25
P079L	Line	20	19	24	20	11	14
	Branch	13	11	13	9	5	8
	Island	3	2	2	2	0	1
	Intersection	0	0	0	1	0	0
		36	32	39	32	16	23
P079R	Line	19	21	13	13	16	20
	Branch	10	12	7	10	9	13
	Island	3	4	2	5	1	2
	Intersection	2	2	1	2	0	0
		34	39	23	30	26	35
P080L	Line	9	10	7	7	10	8
	Branch	4	4	3	3	3	4
	Island	1	1	0	0	0	0
	Intersection	1	0	0	0	0	0
		15	15	10	10	13	12
P080R	Line	8	8	10	12	6	11

	Branch	3	4	6	4	0	6
	Island	1	1	2	1	0	1
	Intersection	0	0	0	0	0	0
		12	13	18	17	6	18
P081L	Line	13	18	7	9	10	12
	Branch	6	9	3	5	1	4
	Island	1	1	1	1	2	1
	Intersection	1	0	2	1	0	2
		21	28	13	16	13	19
P081R	Line	19	12	19	12	13	8
	Branch	12	3	7	3	6	3
	Island	3	1	1	1	1	1
	Intersection	0	2	2	2	0	0
		34	18	29	18	20	12
P082L	Line	22	18	21	14	17	13
	Branch	12	9	13	6	7	5
	Island	4	4	5	3	0	0
	Intersection	2	2	2	3	1	1
		40	33	41	26	25	19
P082R	Line	20	18	18	19	15	14
	Branch	9	9	11	12	9	9
	Island	5	5	5	4	4	4
	Intersection	4	4	3	1	2	2
		38	36	37	36	30	29
P083L	Line	18	18	14	18	15	18
	Branch	9	8	5	8	8	9
	Island	1	1	0	2	1	1
	Intersection	0	1	1	2	0	0
		28	28	20	30	24	28
P083R	Line	8	10	10	10	6	7
	Branch	2	3	2	4	1	2
	Island	1	0	1	3	0	0
	Intersection	1	0	2	2	0	0
		12	13	15	19	7	9
P084L	Line	9	8	6	9	7	8
	Branch	4	4	4	5	3	3
	Island	1	1	1	1	1	1
	Intersection	1	0	0	0	0	0
		15	13	11	15	11	12
P084R	Line	9	8	11	8	9	10
	Branch	5	3	5	3	4	4
	Island	1	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		15	11	16	11	13	14
P085L	Line	15	21	15	7	10	11
	Branch	8	14	7	3	3	5
	Island	1	6	1	2	0	0
	Intersection	0	1	1	2	0	0
		24	42	24	14	13	16
P085R	Line	8	6	6	7	6	6
	Branch	1	0	2	4	1	1

	Island	0	0	0	0	0	0
	Intersection	1	1	0	0	1	1
		10	7	8	11	8	8
P086L	Line	14	14	7	10	13	7
	Branch	8	5	4	4	6	3
	Island	1	1	1	0	0	0
	Intersection	0	0	0	0	0	0
		23	20	12	14	19	10
P086R	Line	16	14	16	14	12	12
	Branch	9	8	8	8	5	5
	Island	2	2	2	2	0	0
	Intersection	0	0	1	0	0	0
		27	24	27	24	17	17
P087L	Line	2	7	4	6	5	5
	Branch	0	3	1	2	2	2
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		2	10	5	8	7	7
P087R	Line	6	8	6	5	6	8
	Branch	2	3	2	2	3	5
	Island	0	1	0	0	0	1
	Intersection	0	1	0	0	0	0
		8	13	8	7	9	14
P089L	Line	13	13	15	15	8	11
	Branch	8	5	8	7	3	4
	Island	2	1	2	2	0	0
	Intersection	1	2	1	1	0	1
		24	21	26	25	11	16
P089R	Line	16	22	17	17	14	20
	Branch	9	13	11	10	6	13
	Island	3	4	3	2	1	4
	Intersection	1	1	1	1	0	1
		29	40	32	30	21	38
P090L	Line	12	16	10	12	12	14
	Branch	6	8	4	5	6	7
	Island	1	1	0	0	1	1
	Intersection	0	0	0	0	0	0
		19	25	14	17	19	22
P090R	Line	14	10	10	10	12	10
	Branch	6	3	3	3	4	3
	Island	1	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		21	13	13	13	16	13
P091L	Line	20	26	23	16	16	20
	Branch	11	15	14	9	11	12
	Island	4	4	5	4	3	2
	Intersection	2	1	1	2	0	0
		37	46	43	31	30	34
P091R	Line	18	19	20	14	12	12
	Branch	7	6	12	9	4	4
	Island	1	1	4	2	1	1

	Intersection	1	1	1	0	2	2
		27	27	37	25	19	19
P092L	Line	8	10	8	9	5	9
	Branch	3	5	3	4	3	4
	Island	0	2	0	0	1	0
	Intersection	0	1	0	0	0	0
		11	18	11	13	9	13
P092R	Line	3	6	4	6	4	4
	Branch	1	2	1	2	1	1
	Island	0	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		4	8	5	8	5	5
P093L	Line	21	29	22	21	14	19
	Branch	10	15	11	13	5	10
	Island	0	2	1	3	0	1
	Intersection	0	0	0	0	0	0
		31	46	34	37	19	30
P093R	Line	15	16	22	17	20	16
	Branch	7	6	12	8	11	8
	Island	2	1	3	2	2	2
	Intersection	2	2	0	1	0	1
		26	25	37	28	33	27
P095L	Line	17	11	9	5	10	9
	Branch	10	5	4	2	4	4
	Island	2	0	0	0	0	0
	Intersection	0	0	0	0	0	0
		29	16	13	7	14	13
P095R	Line	12	9	17	9	7	8
	Branch	6	5	9	5	3	5
	Island	1	1	1	1	0	1
	Intersection	0	0	0	0	0	0
		19	15	27	15	10	14
P097L	Line	13	13	15	11	12	14
	Branch	8	4	8	5	3	4
	Island	1	0	1	1	0	0
	Intersection	0	1	1	0	0	0
		22	18	25	17	15	18
P097R	Line	12	6	3	4	8	7
	Branch	5	2	1	0	2	3
	Island	1	0	0	0	0	1
	Intersection	1	0	0	1	1	1
		19	8	4	5	11	12
P098L	Line	14	11	9	7	8	8
	Branch	7	9	4	2	3	2
	Island	1	2	0	1	0	0
	Intersection	1	0	0	1	0	0
		23	22	13	11	11	10
P098R	Line	13	8	11	9	7	11
	Branch	6	2	5	4	3	6
	Island	2	0	1	1	1	2
	Intersection	1	0	0	0	0	1

		22	10	17	14	11	20
P099L	Line	12	11	7	7	8	7
	Branch	8	6	4	4	5	3
	Island	2	1	1	1	1	1
	Intersection	0	0	0	0	0	1
		22	18	12	12	14	12
P099R	Line	13	10	12	11	7	9
	Branch	4	2	7	6	2	3
	Island	1	0	2	2	0	0
	Intersection	2	2	1	1	1	1
		20	14	22	20	10	13
P100L	Line	14	19	15	18	19	19
	Branch	5	12	6	8	8	10
	Island	0	2	0	0	1	1
	Intersection	0	0	0	1	0	0
		19	33	21	27	28	30
P100R	Line	7	10	6	7	9	12
	Branch	3	2	4	4	2	4
	Island	0	0	1	1	0	0
	Intersection	0	1	0	0	1	1
		10	13	11	12	12	17
TOTAL FEATURE COUNT		3787	3867	3826	3395	2849	3177
AVERAGE FEATURE COUNT		11.41	11.65	11.52	10.23	8.58	9.57

KEY

- Total Feature Count per Individual
- 9MP Daylight ON
- 9MP Daylight OFF
- 3MP Daylight ON
- 3MP Daylight OFF
- VeinViewer Daylight ON
- VeinViewer Daylight OFF